

Towards Development of an Assistive Device for STS Transfer and Ambulation of Healthy Elderly

A Thesis Report

Submitted in partial fulfillment of
requirement for the degree of

Master of Engineering

in

CAD CAM Engineering

by

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(Deemed to be University)

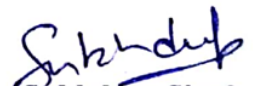
**DEPARTMENT OF MECHANICAL ENGINEERING
THAPAR INSTITUTE OF ENGINEERING AND TECHNOLOGY, PATIALA
JUNE-2018**

DECLARATION

I hereby declare that work done in this report entitled, "Towards Development of Assistive Device for STS Transfer and Ambulation of Healthy Elderly" submitted towards partial fulfilment of requirement for award of Master of Engineering degree in CAD/CAM Engineering in Department of Mechanical Engineering of Thapar Institute of Engineering and Technology, Patiala, is an authentic record of work carried out by me under the supervision and guidance of Dr. Ashish Singla, Associate Professor of Department of Mechanical Engineering, Thapar Institute of Engineering and Technology, Patiala.

This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

Date: 27/06/2018


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This is to certify that above declaration made by the student concerned is correct to the best of my knowledge and belief.


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ACKNOWLEDGEMENT

A venture either big or small requires inspiration and hard work to become a success. While inspiration helps us in initiating the project, hard work helps us clay the methodology and further the project. But there is one more important ingredient which is necessary to keep moving ahead and that is guidance. Without guidance, it is like having a huge but undirected magnitude of energy and working capability. I am highly grateful to my dissertation guide Dr. Ashish Singla for his indefinite support, valuable time and exposure to his knowledge and experience throughout my academic journey till now. He did not only direct and helped me during my thesis work but also helped me evolve as a best version of my own self. He assisted in improving my public speaking and teaching skills. Under his supervision, I was also able to furnish my organizational and management skills as we successfully organized a number of workshops and skype presentations. He also taught me all the skills necessary in academics such as report making, managing course files, art of making effective presentation and efficient lecture delivery.

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ABSTRACT

The life of an individual can be distinguished in 4 major phases, namely infant, adolescence, adult and elderly. With each passing phase, the body accumulates changes which bring forth certain difficulties. But the problems faced by elderly are most severe. Also it has been anticipated by United Nation's report, that world's aged population will see a rise of 56 percent in the next 15 years. Hence there is a definite need to address the problems of elderly in the imminent period. One of the most common difficulties faced by any elderly is reduced mobility due to orthopaedic problems and fall syndrome. There are number of solutions available in the literature to improve mobility of an elderly person i.e. by rehabilitation techniques and equipments. While rehabilitation includes conventional as well as contemporary techniques, the report's primary focus is to discuss the devices being used for STS assistance and ambulation support, and hence proposing a new device which should cover the gaps left unfilled such as natural joint trajectory tracking, portability and simple mechanism.

This report covers the entire process of development of the assistive device, which includes four bar mechanism synthesis with an objective to trail the estimated natural hip joint trajectories obtained using Microsoft Kinect Sensor. Subsequently, producing a 1/4th scaled 3D printed prototype of device after performing a set of virtual dynamic simulations in PTC Creo CAD environment.

Keywords: Assistive device, mobility, STS assistance, ambulation, rehabilitation, four bar mechanism synthesis, joint tracking

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LIST OF ABBREVIATIONS

S. No.	Abbreviation	Meaning
1	STS	Sit to Stand
2	ADL	Activities of Daily Life
3	DOF	Degrees of Freedom
4	PID	Proportional Integration Derivative
5	SMW	Smart Mobile Walker
6	CALOWI	Cassino Low Cost Wired Robot
7	IMU	Inertial Measurement Unit
8	ASR	Advanced Shake Reduction
9	RGB	Red Green Blue
10	CAD	Computer Aided Design
11	SDK	Software Development Kit
12	API	Application Program Interface
13	CG	Centre of Gravity

LIST OF SYMBOLS

Symbols	Meaning
D_K	Distance of Kinect from Chair
a_0	Distance of Crank Ground Connection from Reference
a	Crank Length
b	Ground Length
c	Rocker Length
d	Connecting Rod Length 1
e	Connecting Rod Length 2
f	Connecting Rod Length 3
θ_0	Angle between Reference and Horizontal
θ_1	Angle between Ground Link and Horizontal
θ_2	Angle between Crank and Horizontal
θ_3	Angle between Connecting Rod Length 2 and Horizontal
θ_4	Angle between Rocker and Horizontal
θ_5	Angle between Connecting Rod Length 4 and Horizontal
θ_6	Angle between Connecting Rod Length 1 and Horizontal
x_{di}	Abscissa of desired i^{th} Co-ordinate Position
y_{di}	Ordinate of desired i^{th} Co-ordinate Position
x_0	Abscissa of Crank Ground Connection
y_0	Ordinate of Crank Ground Connection
x_g	Abscissa of Rocker Ground Connection
y_g	Ordinate of Rocker Ground Connection
x_r	Abscissa of Rocker Connecting Rod Connection
y_r	Ordinate of Rocker Connecting Rod Connection
x_f	Abscissa of Follower/Connecting Rod Free End
y_f	Ordinate of Follower/Connecting Rod Free End
e_v	Vicinity Error
F_W	Force Exerted by Individual
T_c	Torque Capacity of Motor
F_L	Force Capacity of Linear Actuator

Ageing is probably one of utmost nightmare for any adult, which in reality is assured and profound to occur. As defined by [1], ageing is the process during which structural and functional changes accumulate in an organism as a result of the passage of time. While to an adult, it brings only the fear of grey hairs, wrinkles, loose skin, etc. But to people in the age group of 60 plus, commonly called ‘the elderly’, it bring forth the worst and that are increased dependency and reduced mobility. Ageing comes packed with a lot of diseases and degenerations, but the one that causes extreme pain and discomfort are orthopaedic problems. Osteoporosis and osteoarthritis is the most general of them. Osteoporosis is a disease of the skeletal system, in which the bone density decreases, thus leading to fragile bones which are more prone to injury related problems such as hip fracture etc. Osteoarthritis on the other hand is majorly associated with joints and vertebral column, which commonly results into restricted motion and deformities.

These ortho problems resulted due to ageing, deteriorate the quality of life of elderly to an extent where they are not only physically affected, but also mentally distressed. It tends to isolate the person from the society, hence discouraging their efforts to keep intact with mobility.

In the current century, a lot of impetus is being given on ageing trends and how to take corrective measure so that a normal human being goes through a smoother ageing process. According to [2], the number of elderly people during 2015 to 2030 is anticipated to rise by 56 percent, which is from 901 million to 1.4 billion. Also it has been predicted that by 2050, the mark will reach 2.1 billion approximately.

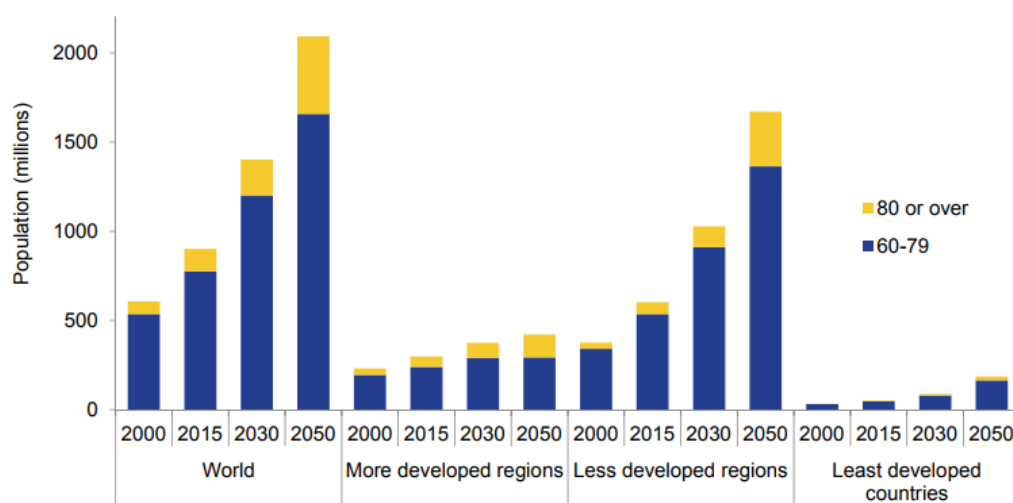


Fig. 1.1 Population Statistics of Aged 60-79 and over 80 [URL: www.un.org]

With the increasing elderly population, it is the need to see through the solution. Medication and surgical operations are the most usual answer to OPD problems. But taking the risk factor of age, these are not a practical option in the case of most of the elderly. To these cases, the ortho-surgeons and doctors suggest rehabilitation as a preferred solution.

Rehabilitation includes sessions of physiotherapy, light exercises, repetition of normal tasks (such as walking, sit-to-stand, stance stabilization, gripping, etc), social interaction and counselling.



Fig.1.2. Conventional Equipments [URL: <http://www.helenmirrenarchives.org>]

Traditionally, rehabilitation may or may not include the use of equipments based upon the level of injury or impairment. Some of the conventional equipments are wheelchairs, canes and walkers etc. But with advancement in technology, equipments are now used at equal extent. The modern equipments include exoskeleton suits, assistive devices etc.



Fig. 1.3 Indego Exoskeleton [3]



Fig 1.4 Mobility Assist [4]

Though both the conventional and modern equipment's main objective is to increase the mobility, but the later can work on particular areas of the body in a more specific way. Talking about the modern rehabilitation equipments, exoskeletons have seen a steeper curve of development as compared to assistive devices. And the reason why exoskeleton are considered more for real time application is it's high degree of portability. Purpose of the present study is to review the existing assistive devices and finding a new solution to increase the portability as well as to make it more user-centric.

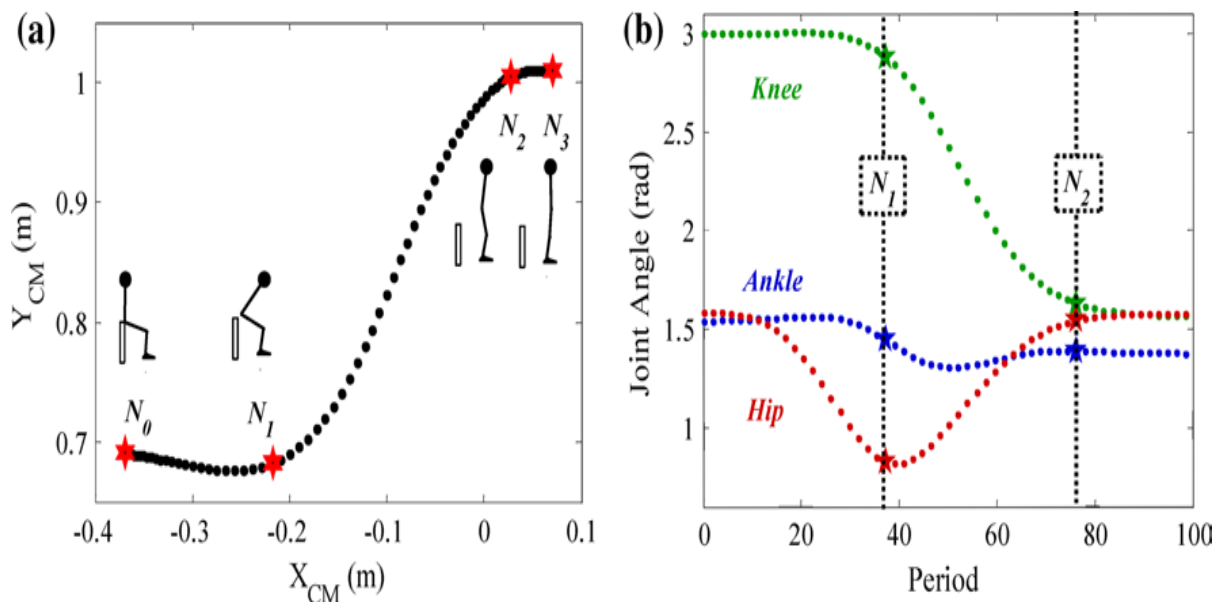


Fig. 1.5 Joint Trajectories during STS [5]

This work deals primarily with STS assistance as it itself is a first step towards mobility. Secondly, the focus will be on ambulation support. For STS assistance, the objectives are set, which have been discussed ahead.

1.1 OBJECTIVES

To develop an assistive device that should be

- Able to assist STS as per the natural human joint trajectories
- Able to support the subject during walking or ambulation
- Actuated in such a way that assisting speed and torques can be varied to enhance improvement of the subject.
- Highly portable
- With a compact and simple mechanism

1.2 METHODOLOGY

To achieve the desired objectives, there was need to define a set methodology which includes sub-objectives to be completed in respective time frames. This work mainly focus on STS support, hence first sub-objective was set to the formation of joint trajectories of a subject during STS transfer, which has been discussed in Chapter 2.

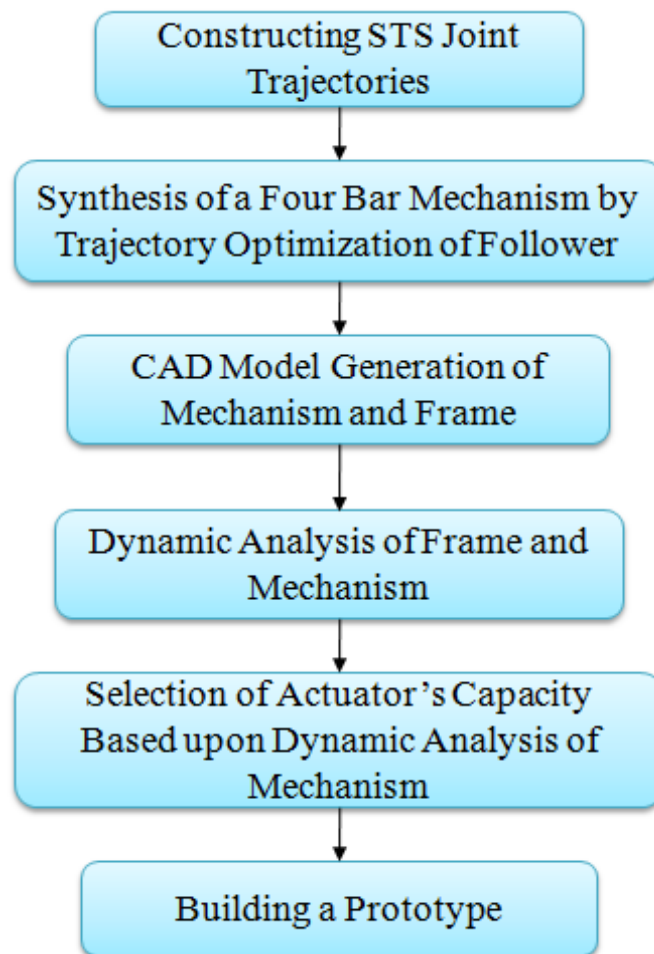


Fig 1.6 Flowchart of Methodology

Secondly, emphasis has been given on four bar mechanism synthesis based upon the obtained joint trajectories which has been explained in Chapter 3. Subsequently in Chapter 4 and Chapter 5, CAD model generation and further objectives impose to build a scaled prototype of the assistive device are discussed., also explained in Fig.1.6. Further in Chapter 6 and 7, outcomes of projects and future scope of work has been presented.

2.1 INTRODUCTION

In this chapter, the state of art of assistive systems, developed to support physically impaired or aged personnel during STS and ambulation is presented. A huge number of researchers have worked in the area of assistive devices for medical applications such as rehabilitation, but cannot be discussed altogether; hence this study is restricted to the ones designed for people under rehabilitation to regain mobility and independence.

2.2 CLASSIFICATION OF ASSITIVE DEVICES

On the basis of literature review, the assistive devices here discussed can be generally classified into four major classes as presented in the flow chart given using Fig. 2.1.

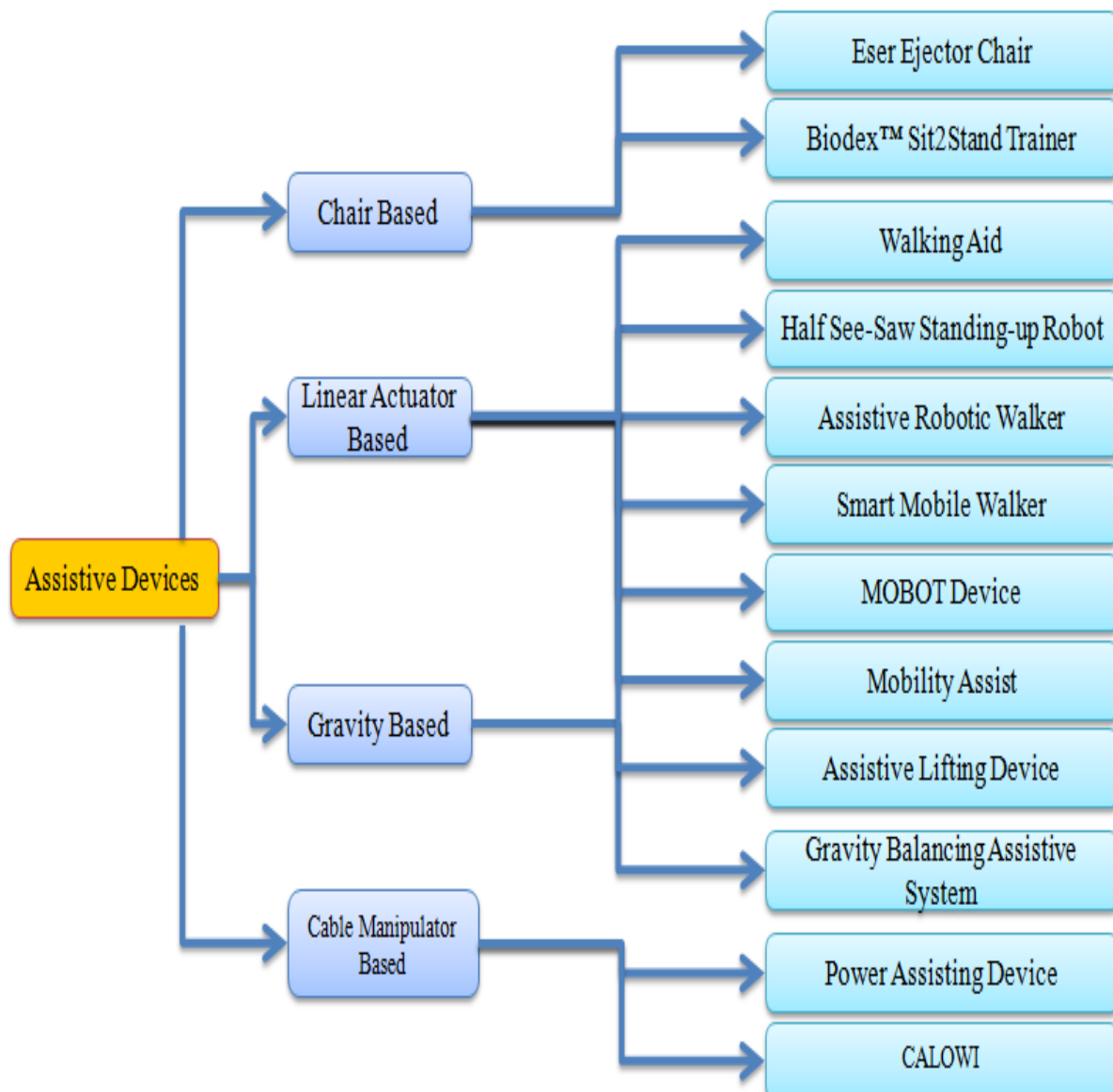


Fig. 2.1 Classification Chart of Assistive Devices

2.2.1 CHAIR BASED DEVICES

a) Eser Ejector Chair (1994, 1998)

This work by Munro et al. [6, 7] aimed to present the effect of using an ejector chair for assisting STS transfer of elderly people with arthritis problem. The ejector chair includes a spring mechanism which provides an upward and forward force to the subject's body, hence leading to rise and taking a stance.



Fig.2.2 Eser ejector chair [6, 7]

Based on the experimental trials presented, they concluded it dangerous for elderly because of high intensity forces being produced by the mechanism. According to the paper, these forces could have caused degeneration of bones of the elderly subject.

Key findings: The device was termed dangerous for elderly people

b) Sit2Stand Trainer

It is a product by a USA based company Biodex also called Squat-assist comprises a support below the buttocks of the subject. The compressive forces produced in the wire passing through a tube beneath the support column provide the upward force for STS.



Fig.2.3 Sit2Stand trainer [8]

2.2.2 LINEAR ACTUATOR BASED DEVICES

a) Walking Aid (2003)

In this work, Médéric et al. [9] emphasised on fall syndrome as a primary motive, which leads to low ADL and low confidence to walk. The robotic system included a 2-DOF mechanism mounted on an active mobile platform. Platform includes 3 caster wheels with 6 actuators for driving and steering. The device used 2 linear actuators for supporting STS transfer. 1st DOF is achieved by locking the front wheel and moving the back wheels forward and other DOF is achieved by 2 linear actuators so as to vary the handle height.

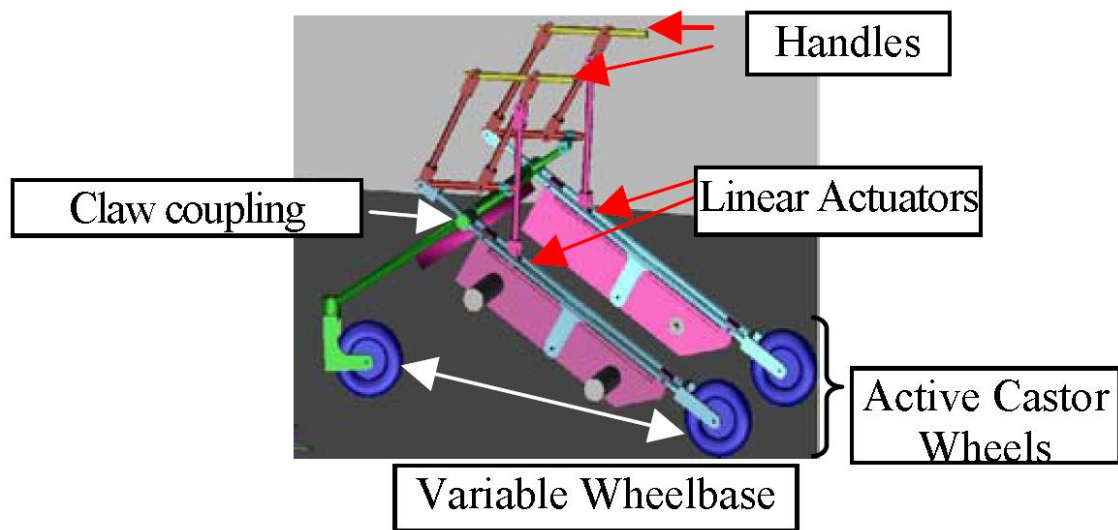


Fig. 2.4 Walking Aid for Elderly [9]

During STS, the moving handles of the device supported the subject. They didn't present a real prototype, but an experimental setup to demonstrate the working is as shown in Fig.2.4.

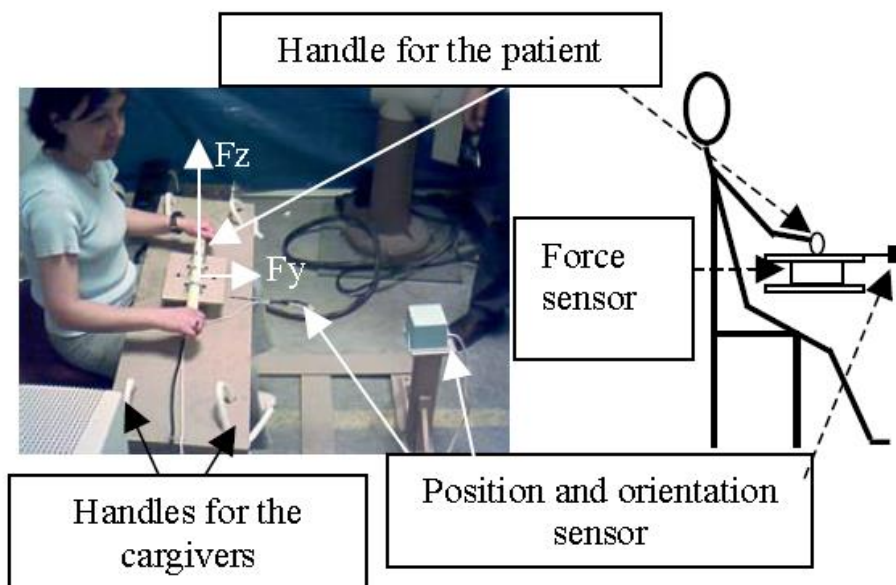


Fig.2.5 Experimental Setup for Walking Aid [9, 10]

Key findings: The device can provide STS support as well as ambulation. It can also be used for handle co-ordinate mapping as well as handle force measurement purpose as depicted in the experimental setup.

b) Half See-Saw Standing-up Robot (2004)

In this work, Kamik et al. [11] built a 3 DOF mechanism for STS transfer. The assistive device resembles a half see-saw structure which comprises a seat for supporting the buttocks of subject. The position of seat in the saggital plane is controlled by two linear hydraulic actuators and orientation being controlled by two master-slave servo cylinders.

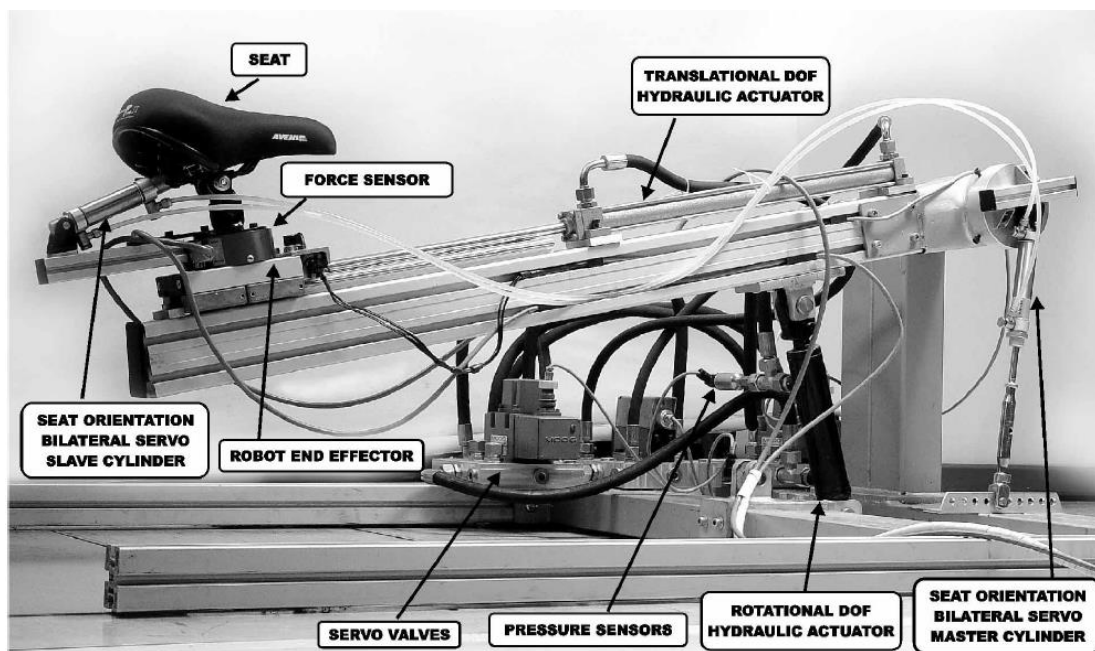


Fig. 2.6 Standing-up Robotic Supportive Device [11]

For controlling the position of seat, they performed inverse kinematics of hip joint using a reference (pre-defined) trajectory and implemented it using a PID controller. The work also presented the demonstration of the setup by a set of experimental trials on paraplegic subjects.

Key findings: The system can comfortably support STS transfer, as per the natural hip joint's trajectory, for people irrespective of height. But as the portability is low, it cannot be used for ambulation. And can only be utilized for repetitive rising up exercise.

b) Assistive Robotic Walker (2009 and 2011)

This proposed assistive device by Chugo et al. [12, 13] consist a support pad with 3 DOF and an active walker. The subject leans on the support pad which is actuated by an assistance manipulator mechanism through 4 parallel linkages as described by Fig 2.8.



Fig. 2.7 Assistive Robotic Walker [12, 13]

The active walker is controlled by 2 brushless motors at the front wheels. The device aims to mimic the manner of support that a specialist nurse provides.

Key findings: Walking as well as STS can be fully supported by the device with high portability and low weight being major advantages. The only limitation is not to implement the natural joint trajectory patterns for designing of linkages.

d) Smart Mobile Walker (2011)

The name Kim et al. [14] gave to their assistive device is smart mobile walker, which was intended to increase the mobility of an elderly using a 3 linear actuated mechanism to control chair rising. The front hub wheel is controlled by a motor for driving and steering to support ambulation. The subject is supported by a plate at the top whose orientation is also controlled using a separate linear actuator.



Fig.2.8 Smart Mobile Walker [14]

e) MOBOT Device (2015)

The objective of this work was to provide most favourable parameters for the mechanical design of a physical assistive device for aged patients suffering from mobility disabilities for ambulation and STS assistance. The device by Hoang and Mombaur [15] has been presented in Fig.2.11, named MOBOT. The model of the device includes 13 rigid bodies where the Control Unit and four wheels belong to the base and the STS-mechanism is represented by the STS frame, Segment 1, Segment 2 and Handle. The rigid bodies of the STS mechanism are connected by 3 rotary joints which allow for three DOF in the sagittal plane. Joints are actuated using electrical linear actuators.

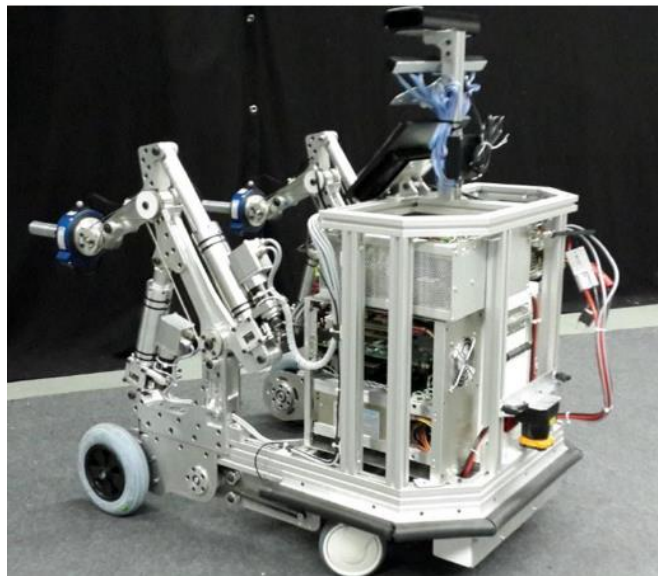


Fig.2.9 MOBOT Device [15]

Key findings: The device is designed, considering natural joint movement patterns for STS assistance. It can also support ambulation to a decent level.

f) Mobility Assist (2017)

This device developed by Purwar et al. [4] includes a novel six-bar mechanism. The mechanism is incorporated in a multi-functional assistive appliance, which helps recuperate mobility of individuals with lower extremity weakness. The 6 bar mechanism trails the J-shaped trajectory of the shoulder-joint and preserve orientation of the supporting bar for the ergonomics and comfort. The proposed single DOF 6 bar mechanism (U.S. patent No.8,468,622 [13]) follows the motion trajectory of the shoulder while holding up the user using a harness under gluteal muscles. Once it achieves the configuration required for standing position, the same device can be deployed as a walker with fall arrest and stability sustainment, thus, eradicating the requirement for extra assistance during ambulation.

Key finding: The device supports both STS and ambulation, as per normal human joint trajectory. It also enables stance stability.

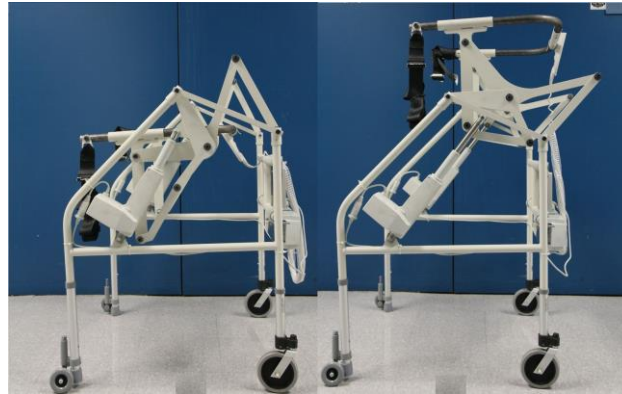


Fig.2.10 Mobility Assist [4]

g) Assistive Lifting Device (2017)

This work aimed to design an assistive device which incorporates an automated lifting technique following human STS transfer trajectory. They implemented a pantograph mechanism to reproduce the STS trajectory. The mechanism as presented in Fig 2.14 is coupled to a structural framework which works as an assistive device for ambulation post lifting.



Fig. 2.11 Assistive Lifting Device [16]

2.2.3 GRAVITY BASED DEVICES

a) Gravity Balancing Assistive System (2006)

The assistive system presented by Abbas et al. [17] is a passive system based on gravity balancing. It is a combination of a 23 Kg mass element, springs and linkages so arranged to leverage the effect of potential energy acquired by mass during the sitting position of subject.

The working can be clearly figured out from Fig. 2.2. When subject initiates the chair rise process, the mass element is pushed by gravity hence in turn pulling the strings and activating the linkages to partial assist the subject for further STS motion.

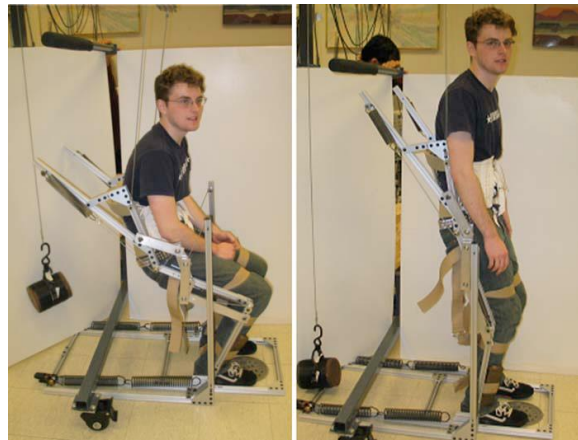


Fig. 2.12 Gravity Balancing Assistive System [17]

Key findings: The system provides partial assistance during STS transfer, but cannot be used for ambulation because of large structural size and a huge mass element swaying at the back of the subject.

2.2.4 CABLE MANIPULATOR BASED

a) Power Assisting Device (2003)

Assistive system discussed by Nagai et al. [18], aimed to increase the mobility of the subject in a four-and-a-half-mat Japanese room. The system presented, comprised a combination of actuated strings attached to a supporting element which could be used for motion guidance and power assistance. The trigger of the system is with user/subject; hence action or movement of support element was customizable.

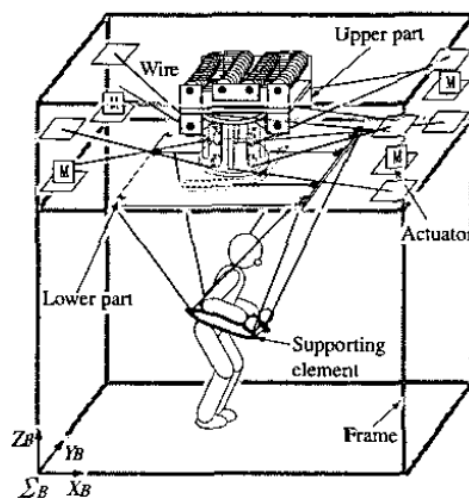


Fig.2.13 Power Assisting Device [18]

Key finding: System can support both STS and walking till a comfortable level. Range of system is a limitation, which narrows down the domain in terms of portability and mobility.

b) CALOWI (2011)

This device by Ottaviano and Castelli [19] presented the application of a cable based manipulator as an aiding or guiding system for impaired or disabled persons. As presented in the Fig.2.9, the subject is supported under the armpit by four cables actuated independently, such that the position of subject can be varied to assist during STS and ambulation.

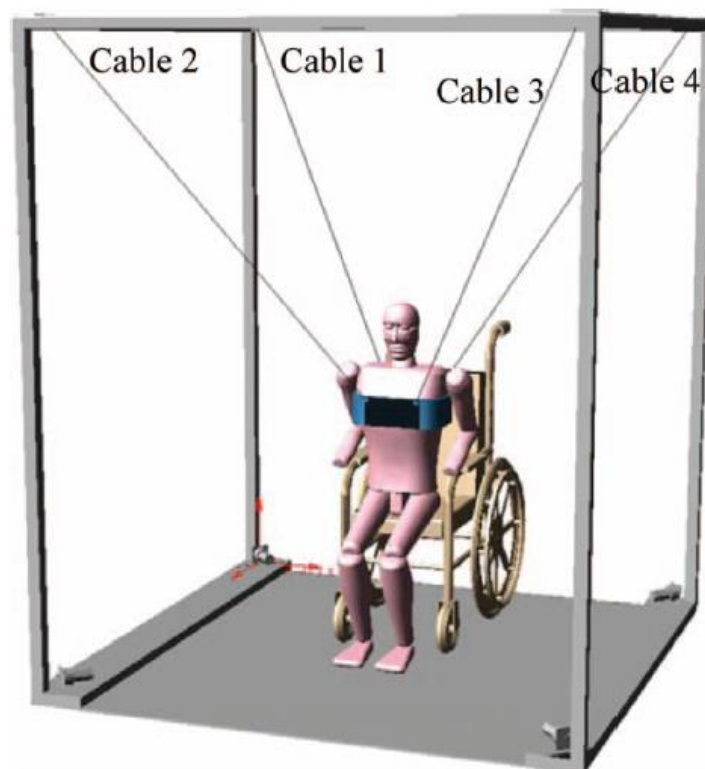


Fig. 2.13 CALOWI Prototype [19]

Their work also supported other modular limb rehabilitation exercises based upon the size of system's frame.

Key finding: Range is limited and depends upon the size of the frame. System can assist both during STS and walking, hence can be used for rehabilitation exercises.

2.3 SUMMARY

Using the above discussions, some important features and key findings were extracted which have been used for comparison of assistive devices as presented in the Table 2.1. The following comparison highlights the possible gaps and limitations, which has been used to clear the motives and objectives of this report.

Table 2.1 Comparison Between Devices

Type	Device	STS Assistance	Ambulation Support	Portability	Follow Natural Trajectory Patterns
Chair Based	Eser Ejector Chair	Yes	No	Low	No
	Sit2Stand Trainer	Yes	No	Low	Yes
Gravity Based	Gravity Balancing Assitive System	Yes	No	Very Low	No
Cable Manipulator Based	Power Assisting Device	Yes	Yes	Very Low	No
	CALOWI	Yes	Yes	Low	Yes
Linear Actuator Based	Walking Aid	Yes	Yes	High	Hand Trajectory
	Half See-Saw Standing-up Robot	Yes	No	Low	Hip Joint Trajectory
	Robotic Walker	Yes	Yes	High	Shoulder Trajectory
	SMW	Yes	Yes	High	No
	MOBOT	Yes	Yes	Medium	Hand Trajectory
	Mobility Assist	Yes	Yes	High	Shoulder Joint Trajectory
	Assistive Lifting Device	Yes	Yes	High	Hip Joint Trajectory

It can be seen from Table 2.1 that mostly all of the devices provide STS assistance but major of them doesn't follow the STS trajectory. While some of the devices are highly portable, some provides very low portability with zero ambulation support. Hence, it can be concluded from this chapter that there is a need of a device that could provide high portability, STS assistance with natural joint trajectory, good ambulation support and simple mechanism. In the upcoming chapter, joint trajectories of an individual has been discussed to initiate as per the methodology planned.

3.1 INTRODUCTION

As discussed in the previous chapter, there is a need to develop an assistive device that could assist STS transfer by following natural joint trajectories. Hence, STS joint tracking was the initial and the most important step for achieving the desired objectives. In the current chapter, at first STS terminologies are brought up, subsequently followed by discussion of joint tracking techniques and finally evaluating joint co-ordinate position data.

3.2 STS - GENERAL TERMINOLOGIES

Study of STS motion involves both mechanical as well as biological terminologies. To understand it through the depth, knowledge of very basic biological terms was necessary. The vocabulary of both mechanical as well as biology is vast, hence our explanation is limited to only the terms associated with lower limbs, bones and joints which are ahead associated with STS transfer.

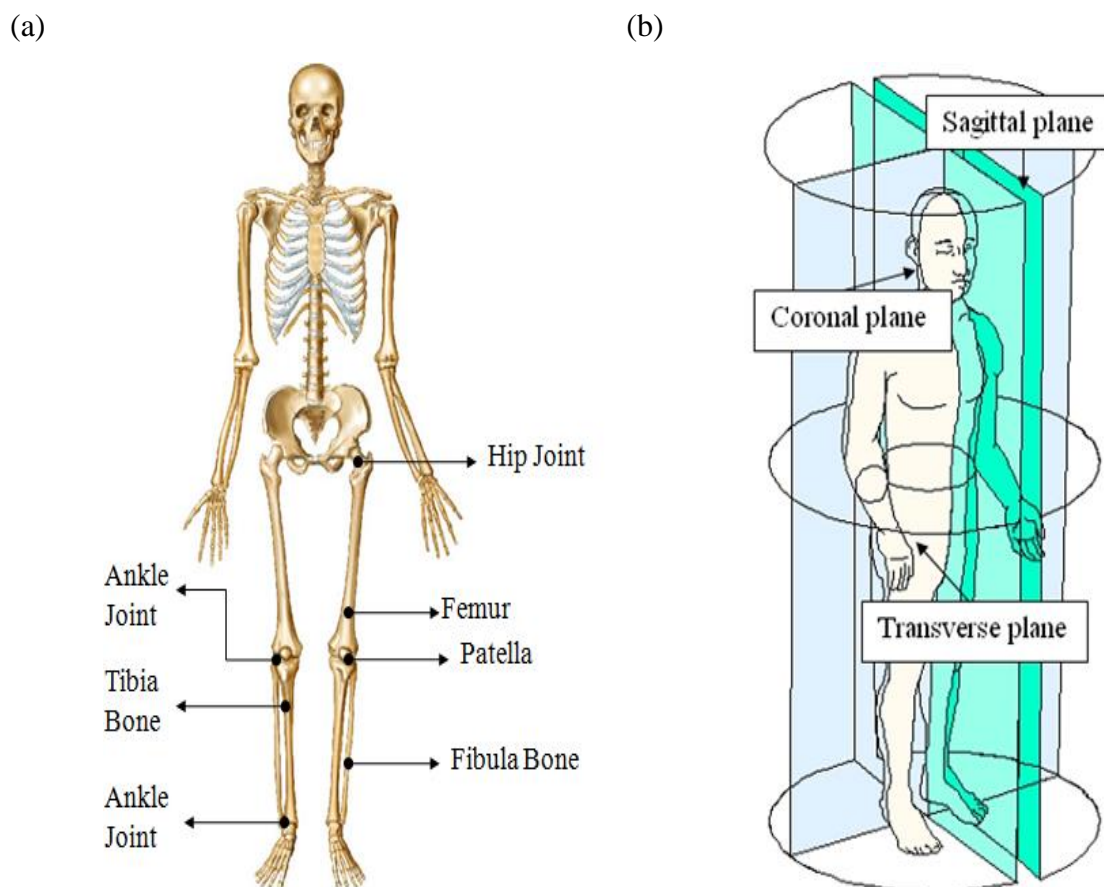


Fig 3.1 (a) Human Skeleton System Human Skeleton [URL: www.uocodac.com] (b) Anatomical Planes of Human Body [URL: www.atlasofanatomy.com]

As presented in Fig.3.1 (a), the shin limb that is a connection between ankle and knee joint consist of two bones, fibula and tibia. While thigh limb consist only one bone called femur bone, it connects hip joint to knee joint.

3.3 JOINT TRACKING METHODS

Realizing the motion is core objective of a human eye, but it can only observe the motion, it cannot quantitatively analyze the motion. For the realization of quantitative displacement during motion of a human body, cameras or micro-electronic sensors are deployed to obtain co-ordinate data taking a frame of reference. The methods that can be used to obtain such co-ordinate data of human joints are presented in Fig. 3.2.

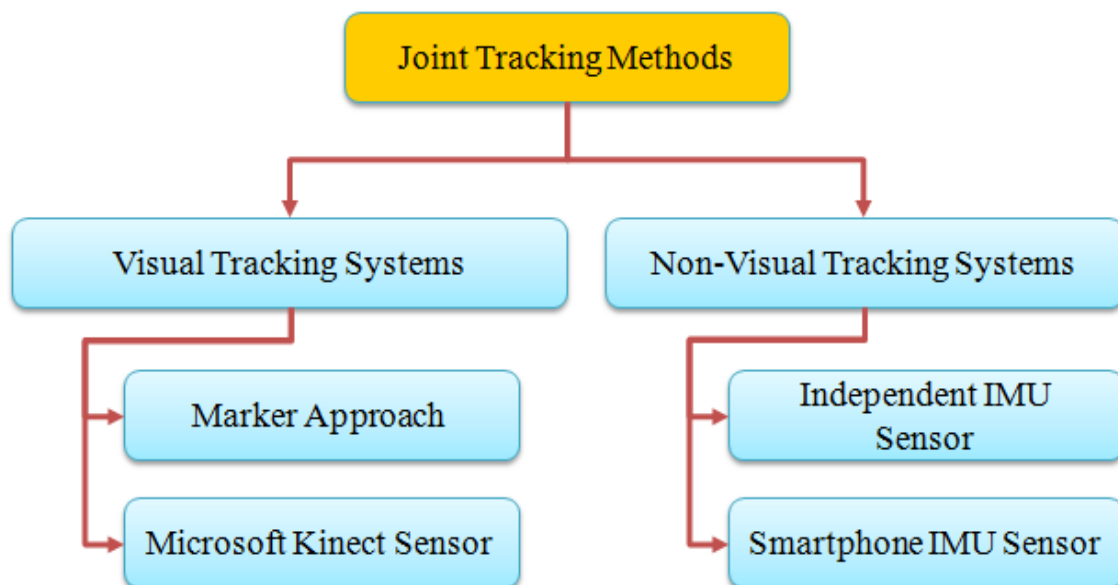


Fig 3.2 Human Joint Tracking Methods Used

3.3.1 VISUAL TRACKING SYSTEMS

a) Marker Approach

In this approach, subject has to wear a marker suit as presented in Fig 3.3. The subject then is introduced to high resolution cameras which produce a set of information in terms of frames and images. Markers on the suit represent the points of interest (majorly joints), tracking of which is done by image processing techniques.

In the context of joint tracking during STS, Nuzik et al. [20] used marker approach. Their setup comprised a Bolex camera and electronic graphics calculator interfaced with a Texas Instruments Silent 700 ASR electronic data terminal to record x and y coordinates on digital magnetic tape cassettes.



Fig 3.3 Human Wearing Marker Suit [URL: www.sdm.scad.edu]

b) Microsoft Kinect Sensor

The Microsoft Kinect is a set of sensors developed as a device for the Xbox 360 gaming console purpose. It uses image, audio, and depth sensors to sense movements, to identify faces, and to recognize speech of players, allowing people to play games using their own bodies as controls. Unlike earlier attempts at gesture-based or movement-based controls, it does not need the person to carry any kind of accessory to enable the gadget to detect the player's actions. The depth, image, and audio sensors are incorporated in a horizontal bar attached to a base with a pivot that allows it to alter the sensor bar orientation in vertical plane.



Fig 3.4 Microsoft Kinect Sensor [21]

An RGB camera obtains a 2-dimensional color video of the view that is used in Microsoft's gaming software for facial identification and for presenting images on the screen during play.

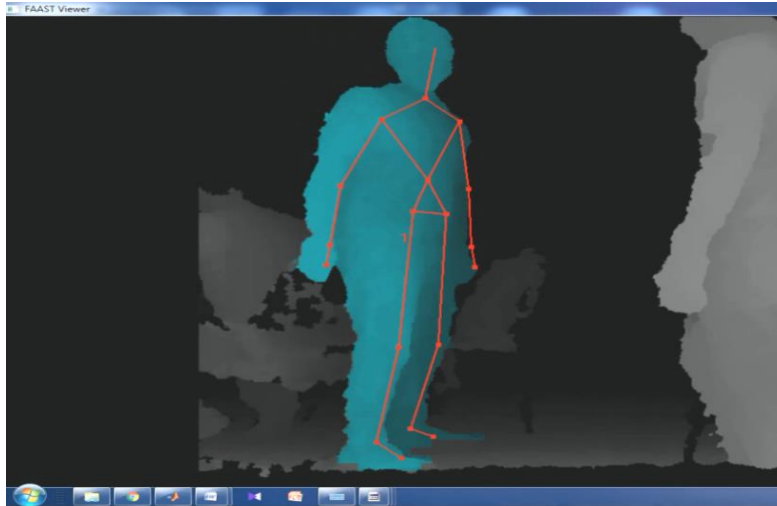


Fig 3.5 FAAST Skeleton Tracking [21]

An array of 4 microphones situated along the bottom of the horizontal bar enables speech recognition with acoustic source localization, ambient noise suppression, and echo cancellation. The depth component of the Kinect is realized using two infrared sensors. Together these sensors are the foundation for gesture recognition and skeleton tracking. The infrared light projector throw a grid of infrared light on the field of view, and a depth map is formed on the basis of the rays that the sensor obtain from reflections of the light off of objects in the sight. The depth map indicates the distance of the surfaces of objects from the viewpoint of the Kinect sensor.

The work by [23] and [24] supports the ability of Kinect sensor to track the joints during STS transfer.

3.3.2 NON - VISUAL TRACKING SYSTEMS

a) Independent IMU Sensor

This approach makes the use of independent Inertial Measurement Unit sensors (electromechanical and electromagnetic sensors) such as G-Link as presented in Fig 3.6.

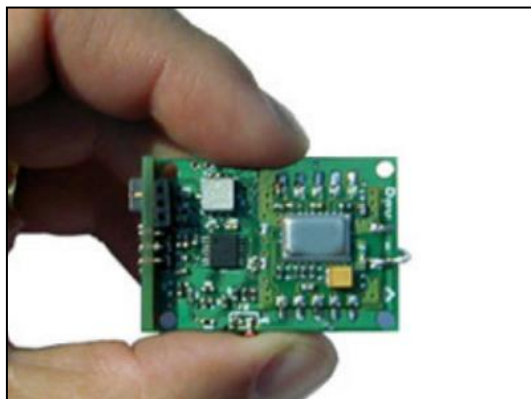


Fig. 3.6 A G-Link Unit [URL: <http://www.microstrain.com/>]

The subject is to wear these sensors on their body for if motion tracking is the desired objective, as discussed in Fig. 3.7. Vohralik et al. [24] also demonstrated the reliability of smartphone in measuring joint angles instead of using independent digital inclinometer. Their demonstration assessed participant's dorsiflexion using a weight-bearing lunge test.

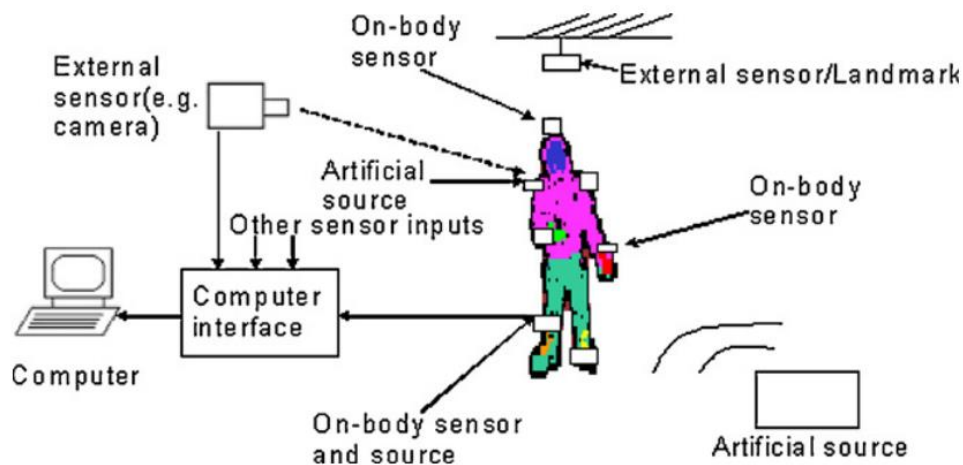


Fig. 3.7 An Illustration of a Proposed Human Movement Tracking System [26]

b) Smartphone IMU Sensor

Nowadays smartphone consist various types of sensor. The list includes touch sensor, proximity sensors and IMU sensors as well. For joint tracking, specifically accelerometer is used. The working of the system is very much similar to independent IMU sensors, difference being the smartphone are more widely spread, simple to use and data deduction is easy. This technique has been specifically used for hip joint tracking during STS transfer only.

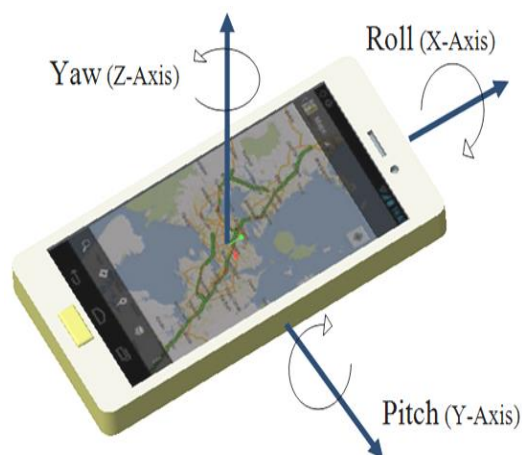


Fig. 3.8 Description of Axes and Angles in Smartphone Accelerometer.

In smartphones, commonly a tri-axial accelerometer is present with varying response characteristics and configuration based upon the manufacturer. The sole purpose of installing an accelerometer in smartphone was portrait switching, compass and gaming applications.

However, in recent smartphones, its purpose is extended for image stabilization, anti-blur capturing, step counters and gait activity recognition like walking etc. An accelerometer in a commercially available smartphone provides an output in terms of gravitational acceleration i.e. -1g to +1g on every enabled axis.



Fig. 3.9 Description of Attachment of Smartphones on Lower Limbs using PTC Creo Manikin [27]

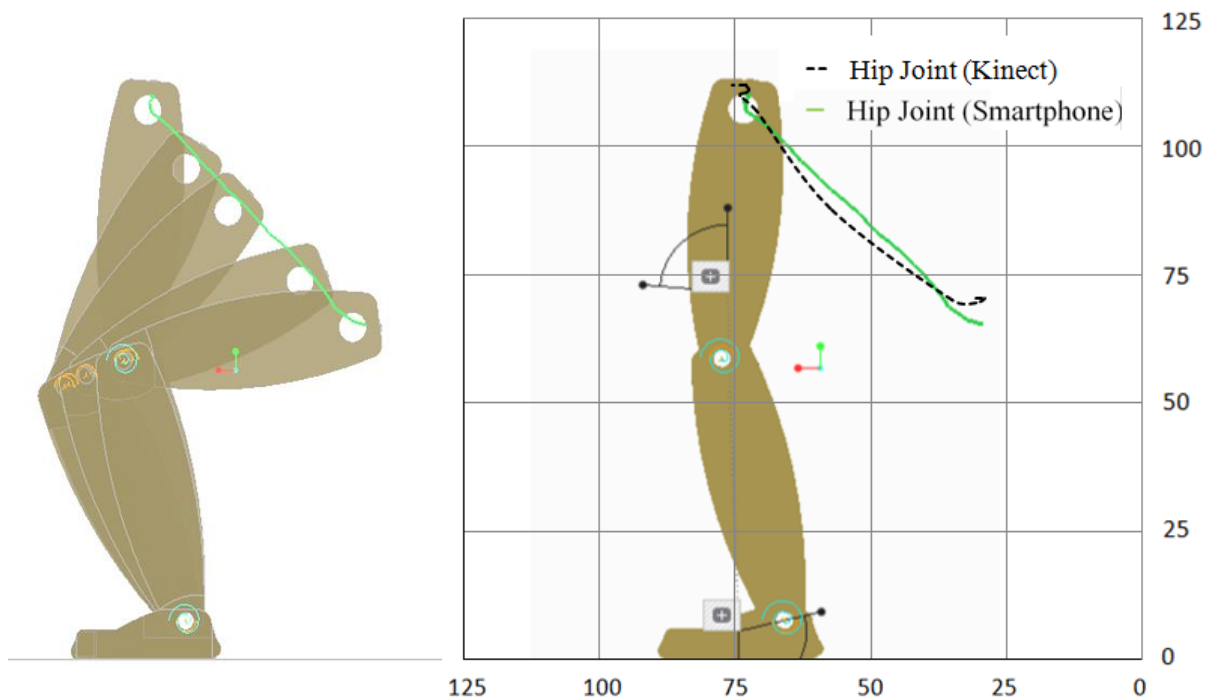


Fig. 3.10 Hip Joint path by Microsoft Kinect and CAD position analysis (using angular readings from Smartphone)

3.4 STS JOINT TRAJECTORY FORMATION

Joint trajectories are time bound paths followed by the human joints during basic ADL's (Activities of Daily Life) and can be obtained using co-ordinate mapping of human skeleton. For co-ordinate mapping during STS, Microsoft Kinect have been specifically used as a primary method and smartphone IMU sensor as secondary approach.

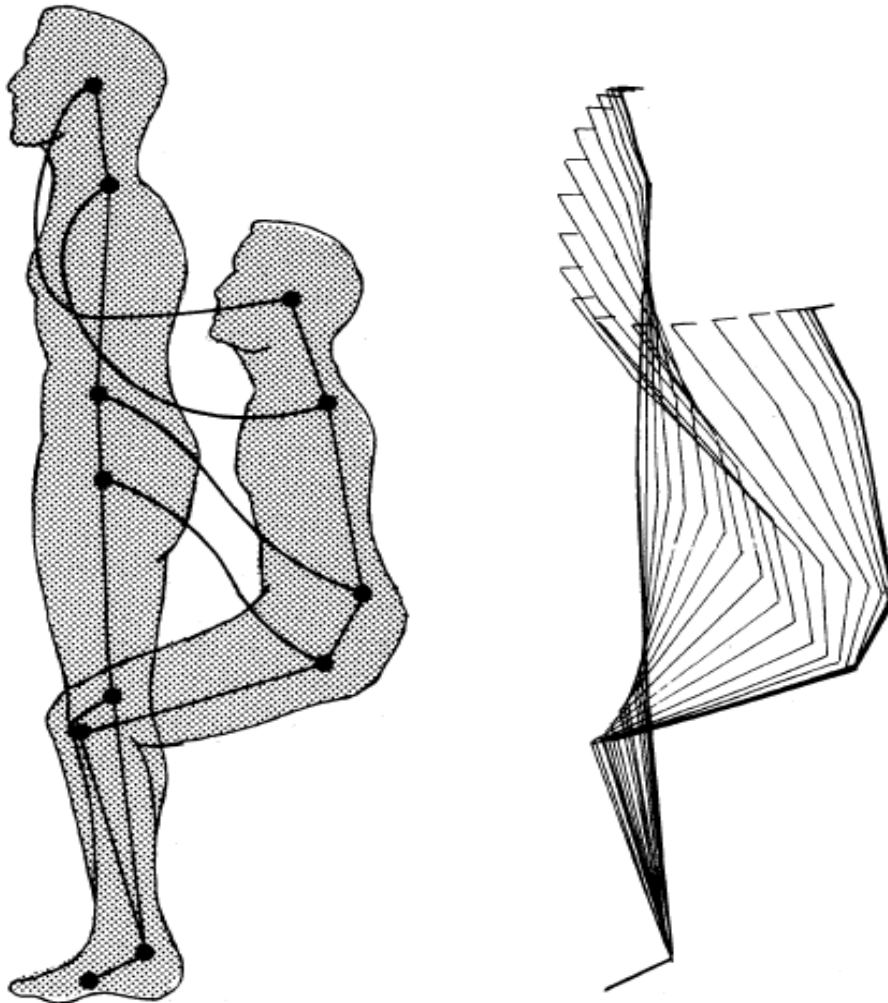


Fig 3.11 STS Trajectory in Saggital Plane [20]

3.4.1 VIRTUAL ENVIRONMENT

a) Kinect Drivers and SDK

The Kinect was formerly distributed just for use with the Xbox 360 and the games developed by Microsoft for this platform. But, since rehabilitation facilities were not likely to have an Xbox at their disposal, an application developed for a computer was more realistic. Kinect is accessible on windows with a SDK that supports development in C++, C#, VB.NET and MATLAB. Its API let users to extract and work with depth, colour and skeleton tracking data.

One of the imperative features given by Kinect SDK is the skeletal tracking, and that data have been widely used in order to obtain human limb data. Skeletal tracking is a feature of Kinect SDK and it enables Kinect sensor to identify human joints as presented in Fig 3.12. To recognize users facing the sensor or if the user is in a standing or sitting pose, sophisticated tracking algorithms are designed and implemented.

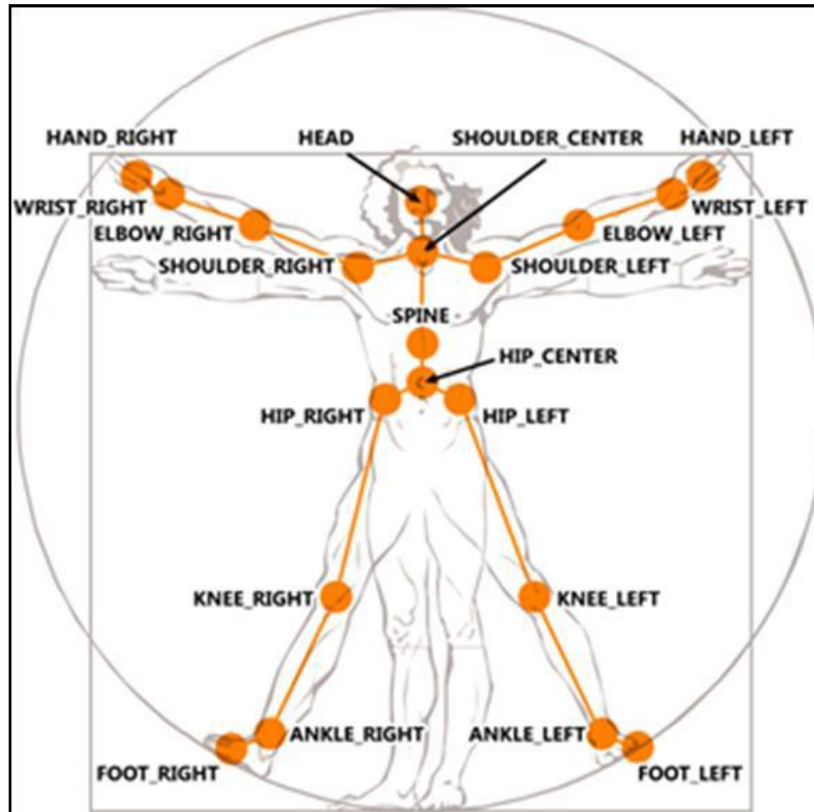


Fig. 3.12 Microsoft SDK Skeleton [28]

b) MATLAB Image Acquisition Toolbox

Image Acquisition Toolbox™ supply functions and blocks that enable the connection of industrial and scientific cameras to MATLAB [29] and Simulink®. It includes a MATLAB application that allows you to interactively spot and configure hardware properties. The toolbox allows acquisition modes such as processing in-the-loop, hardware triggering, background acquisition, and synchronizing acquisition across a number of devices.

The data generated by Kinect using MATLAB is available in two forms. First being the image indices data and second being the real world co-ordinate data. For the purpose of experimentation, image indices data have been used to avoid alteration in coronal plane. The output of MATLAB after data acquisition from Kinect can be realized by Fig. 3.13, in which particularly hip, knee and ankle joints are being tracked.

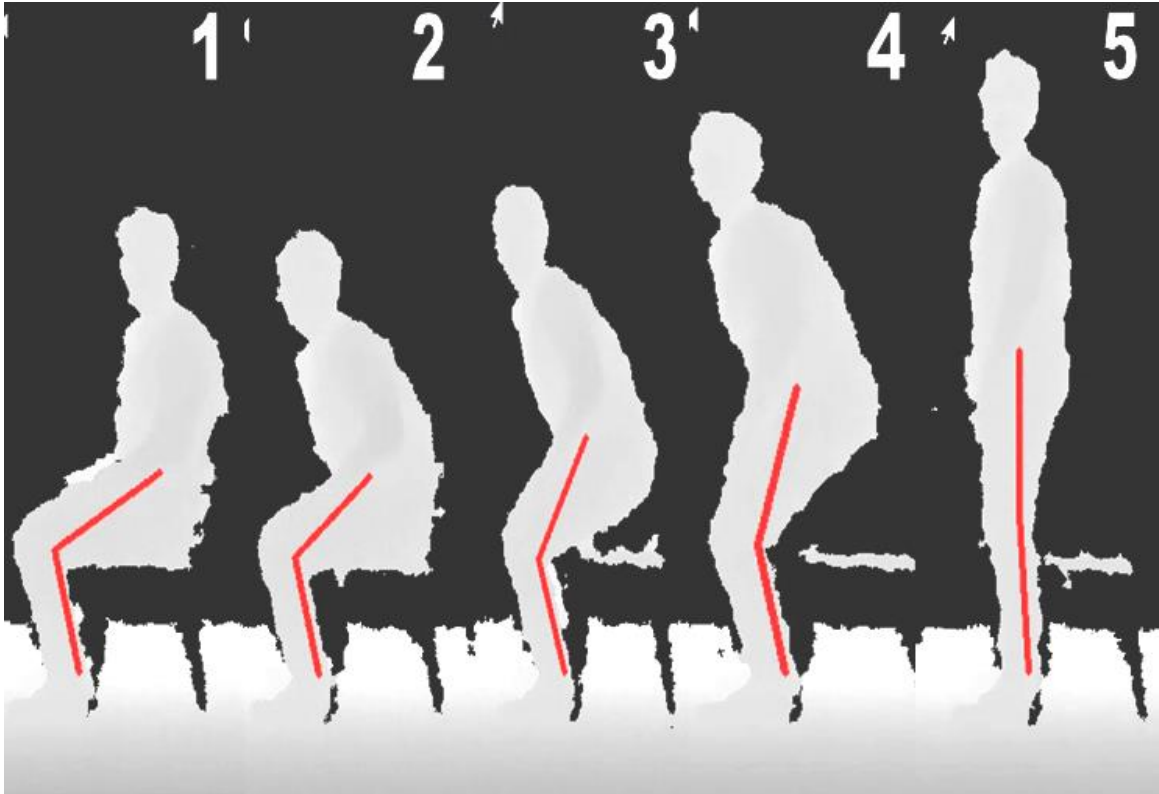


Fig.3.13 Image acquisition during Microsoft Kinect session using MATLAB

3.4.2 PHYSICAL ENVIRONMENT

a) Subject Specification and Protocols

During data logging, subject was informed to rise from an armless chair with a height of 50 cm in a span of 5 seconds. The subject was told to cover the span such that to start the motion at approximately 1.7 seconds and complete it at 4 seconds with 1 second for stance stability. The subject was also directed to keep the feet at a distance of 5 cm from the chair to maintain consistency of the experiment.

Table 3.1 Specification of Subject

Parameter	Value
Height	178 cm
Weight	90 Kg
Thigh Limb Length	52 cm
Shin Limb Length (Tibia Bone)	48 cm

The chair was placed at a distance of 2.5 m (Labelle in [23] discussed 2.5 m as an optimal distance for joint tracking) from the Kinect hardware as explained in Fig. 3.14. Kinect was adjusted at a pitch angle of 2° throughout the recording session.

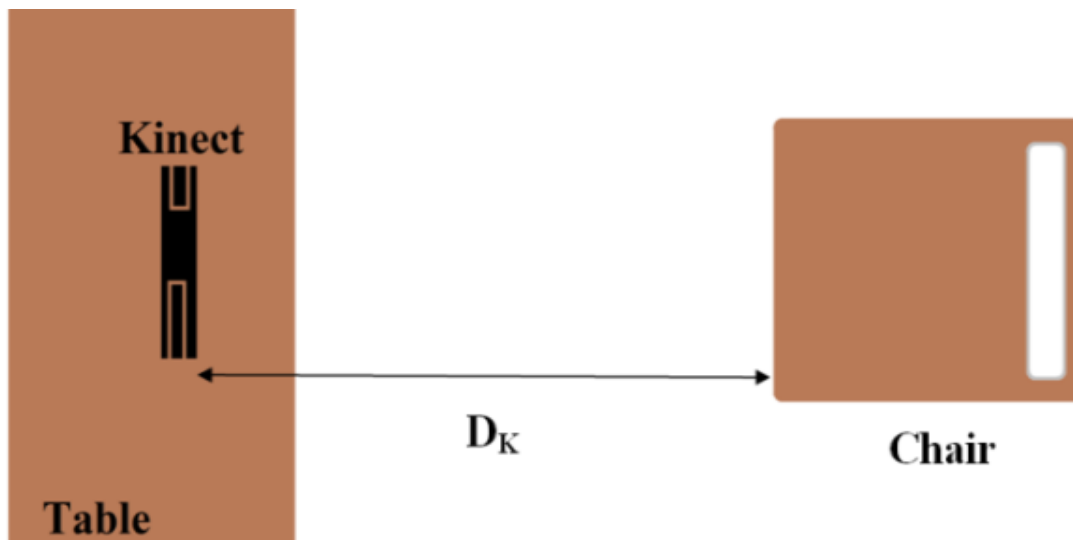


Fig. 3.14 Microsoft Kinect Setup, where D_K is the Distance of Kinect from Chair

3.4.3 HIP JOINT TRAJECTORIES

Using the joint co-ordinate data obtained from Kinect, three trajectories were constructed as shown in Fig. 3.15. Subject was told to perform chair rise in the same manner for three times with same chair and protocols. Minor deviations between the trajectories can be observed due to various noise factors associated with virtual and physical environment such as human error to perform exact task.

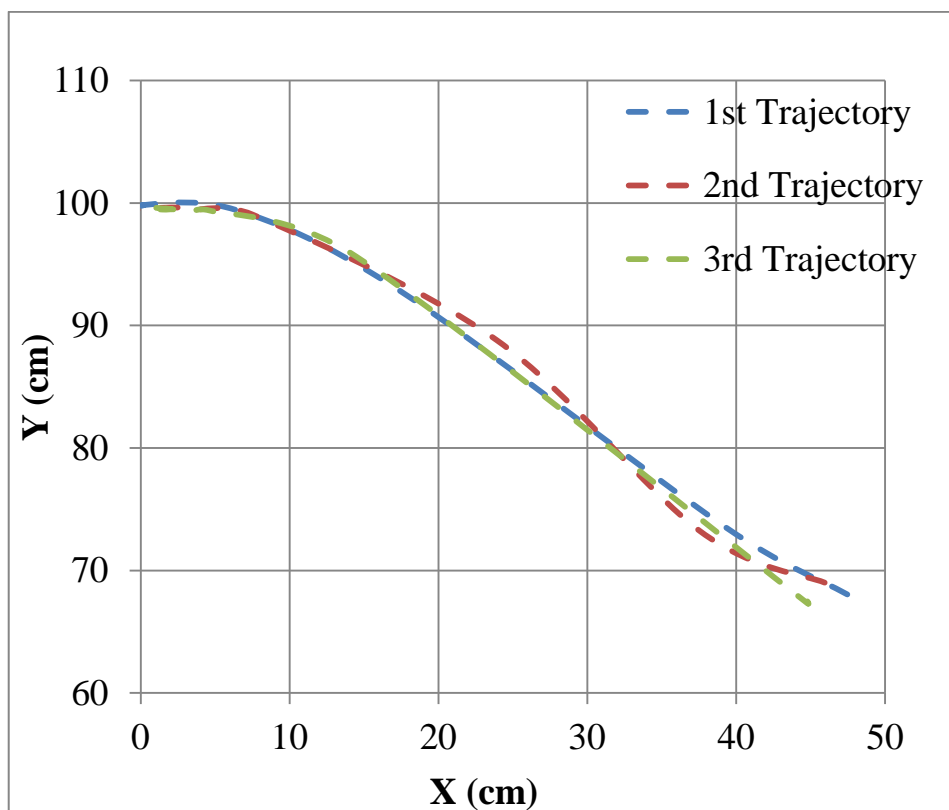


Fig. 3.15 Plot of Hip Joint Trajectories of Subject during STS

3.5 SUMMARY

In this chapter, different joint tracking techniques have been discussed and hip joint trajectories during STS were evaluated for an individual having mass specification given in Table 3.1, using Microsoft Kinect Sensor. It was found that the hip joint follows a mirrored italic letter “s” like structure. The coming up chapter discusses the use of quantitative data so obtained to develop a mechanism that could trail the similar hip joint trajectory.

4.1 INTRODUCTION

Mechanism can be defined as a closed loop of link or kinematic chain, in which any one link is fixed and the state of other links can be controlled by input to one of the link. Mechanisms are used to manipulate the input motion into a desired motion. Most general example of a mechanism is a crank rocker which converts linear motion into rotary motion. In this chapter, the steps involved in synthesis of four bar mechanism has been discussed in details, subsequently calculating the link lengths to produce a mechanism to imitate hip joint trajectory evaluated in the previous chapter.

4.2 MECHANISM SYNTHESIS

The procedure by which a specific mechanism type and appropriate dimensions of the linkages are recognized based upon the desired motion/trajectory is called mechanism synthesis. Mechanism synthesis includes either a graphical or an analytical approach. Graphical approach comprises velocity and acceleration diagram, while analytical approach comprise deciphering displacement analytical equation either formulated using trigonometry or vector algebra.

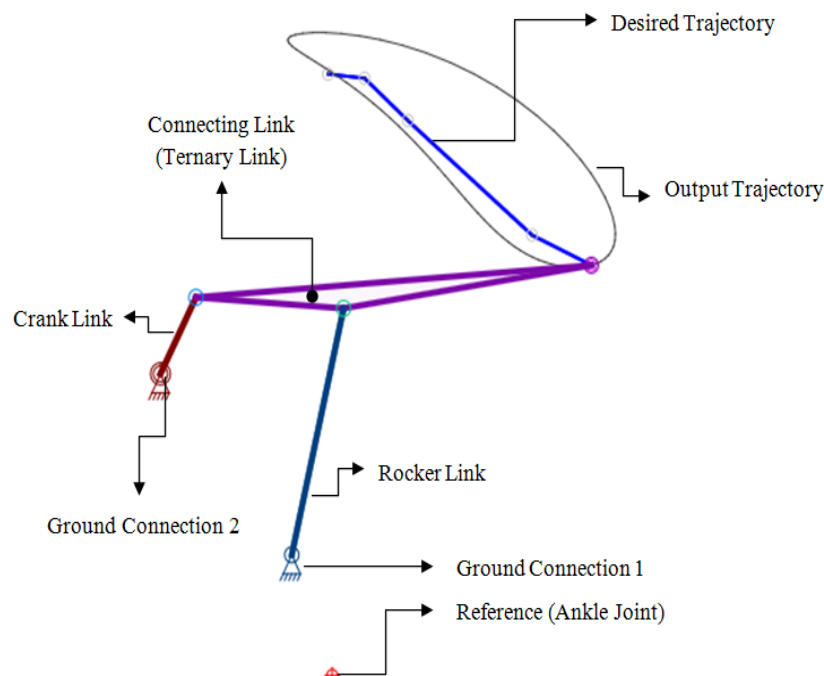


Fig.4.1 Four Bar Mechanism Synthesised using Linkage [30]

In the present study, desired motion has been formed using STS joint trajectory formation presented in Fig.3.15. An average trajectory with the help of 5 synced position coordinate data out of three trajectories was evaluated to simplify the synthesis. Here, synthesis

of a four bar mechanism have been done to satisfy the joint co-ordinate data obtained using Kinect. To initiate with synthesis, Linkage [30] which is mechanism design and simulator software have been used. At first, a hit and trial method was tried to make the follower trail the desired hip joint position as presented in Fig. 4.1. The hit and trial method solved for us, the issue of identification of mechanism type, that was found to be a crank and rocker mechanism with a connecting ternary link. But to satisfy the 5 different co-ordinate positions, mathematical model of crank rocker mechanism was needed to be developed, subsequently solving it to find the link lengths of mechanism.

4.3 MATHEMATICAL MODEL OF CRANK ROCKER MECHANISM

The mathematical model is discussed using two approaches, first being the exact solution approach and second being an approximate solution approach. In exact approach, the model have been formulated using vector algebra. While in approximate approach, Pythagoras theorem and Trigonometric framework have been applied.

In Fig. 4.2, the different link lengths of the mechanism are presented, which were to be evaluated in lieu to obtain the desired trajectory of follower end of ternary link, where a,b,c represents crank, ground and rocker dimensions respectively. While d, f represents connecting ternary link dimension and a_0 is length of crack-ground connection from reference (ankle joint).

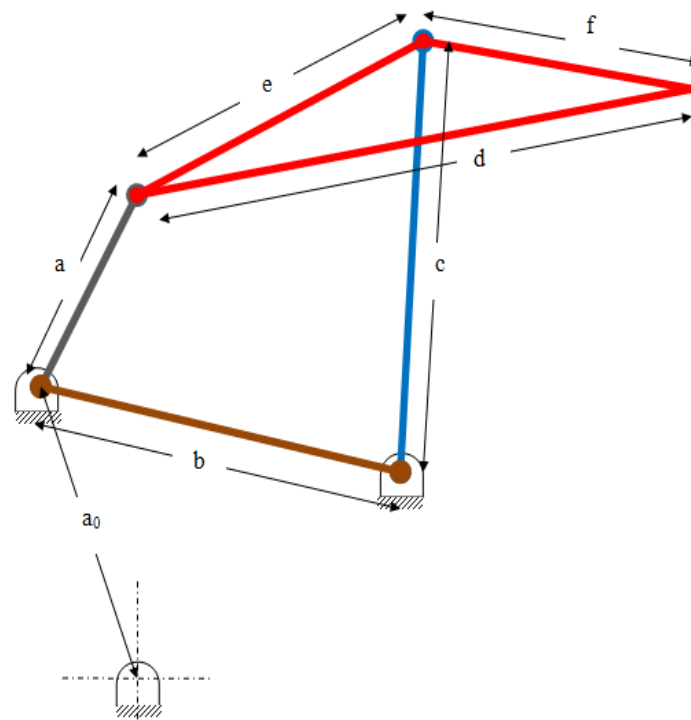


Fig.4.2 Four Bar Mechanism Link Diagram for Developing Mathematical Model

4.3.1 EXACT SOLUTION APPROACH

As discussed earlier, in exact solution approach, mathematical model using vector algebra have been developed, which follows a flow diagram presented in Fig.4.3. The model consists of two different types of equations, namely orientation and position co-ordinate equations. These equations are clubbed together to form a system of non linear simultaneous equations which is solved using MATLAB solvers like *solve* and *fsolve*. The size of the system of simultaneous equation is governed by number of position co-ordinates to be satisfied. For example, 5 co-ordinates data forms a set of 15 equations, in which 10 equations are position co-ordinate equations and 5 equations are orientation equations. Similarly, 4 co-ordinate data forms a set of 12 equations.

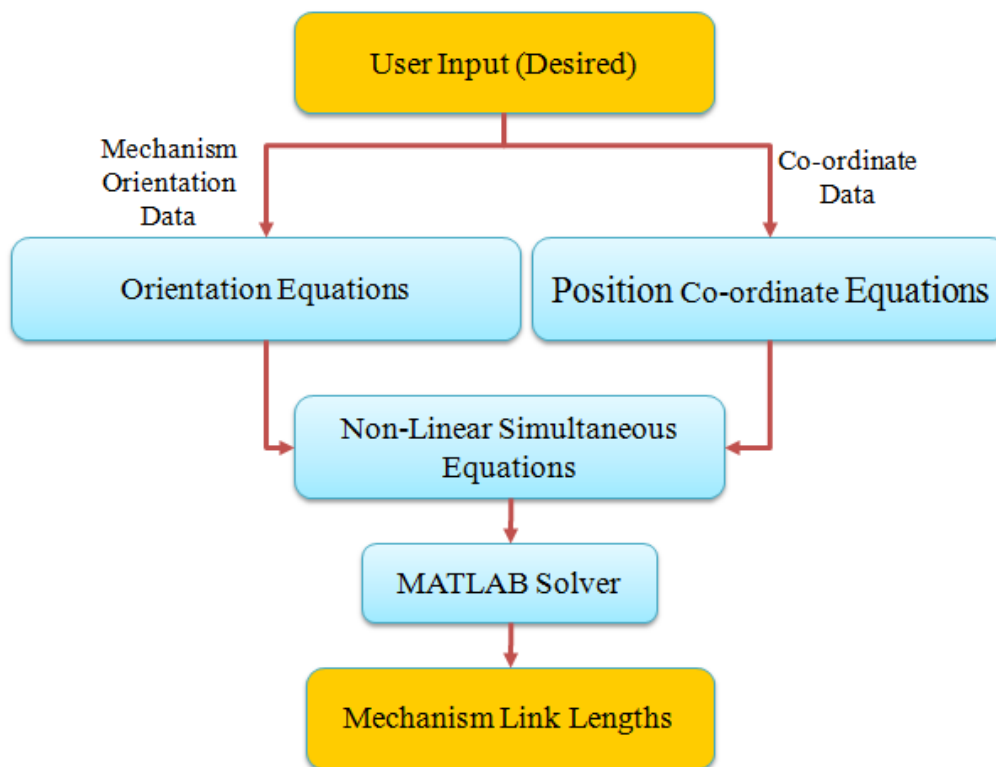


Fig.4.3 Flow Chart for Exact Solution Approach

In vector loop ABDC presented in Fig. 4.4, the position vectors can be mathematically written as given in Eq. 1, which can be further written as given in Eq.2.

$$\vec{R}_2 + \vec{R}_3 = \vec{R}_1 + \vec{R}_4 \quad (1)$$

$$ae^{i\theta_2} + ee^{i\theta_3} = be^{i\theta_1} + ce^{i\theta_4} \quad (2)$$

For vector loop CED, the position vectors can be written as Eq. 3, which is be resolved and given in Eq.4.

$$\vec{R}_5 + \vec{R}_3 = \vec{R}_6 \quad (3)$$

$$fe^{i\theta_5} + ee^{i\theta_3} = de^{i\theta_6} \quad (4)$$

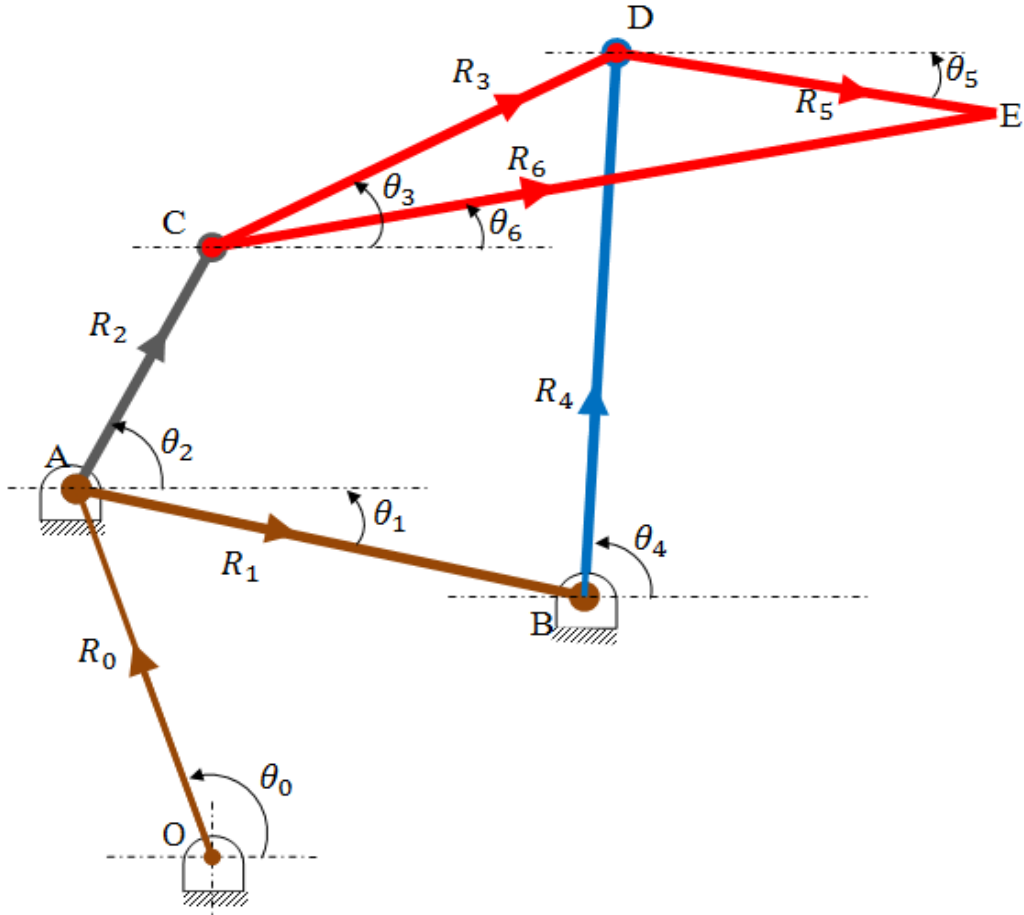


Fig.4.4 Four Bar Mechanism Vector Representation 1

Solving Eq.2 and Eq.4, obtained expression is presented in Eq. 5 which is expanded using Euler Identity and is given using Eq.6.

$$ae^{i\theta_2} - be^{i\theta_1} - ce^{i\theta_4} - fe^{i\theta_5} + de^{i\theta_6} = 0 \quad (5)$$

$$a(\cos \theta_2 + i \sin \theta_2) - b(\cos \theta_1 - i \sin \theta_1) - c(\cos \theta_4 + i \sin \theta_4) - f(\cos \theta_5 - i \sin \theta_5) + d(\cos \theta_6 + i \sin \theta_6) = 0 \quad (6)$$

Now separating the real and imaginary part from complex algebra Eq.6, equations obtained are given using Eq.7 and Eq.8 respectively.

$$a(\cos \theta_2) - b(\cos \theta_1) - c(\cos \theta_4) - f(\cos \theta_5) + d(\cos \theta_6) = 0 \quad (7)$$

$$a(\sin \theta_2) + b(\sin \theta_1) - c(\sin \theta_4) + f(\sin \theta_5) + d(\sin \theta_6) = 0 \quad (8)$$

Now Eq. 7 and Eq.8 are squared on both sides and added to each other to obtain the expression presented using Eq.9 which is used to satisfy the orientation of follower and is termed as orientation equation.

$$c^2 = a^2 + b^2 + d^2 + f^2 - 2ab (\cos(\theta_1 + \theta_2)) + 2ad (\cos(\theta_2 - \theta_6)) - 2af (\cos(\theta_2 + \theta_5)) - 2bd (\cos(\theta_1 + \theta_6)) + 2bf (\cos(\theta_1 - \theta_5)) - 2df (\cos(\theta_6 + \theta_5)) \quad (9)$$

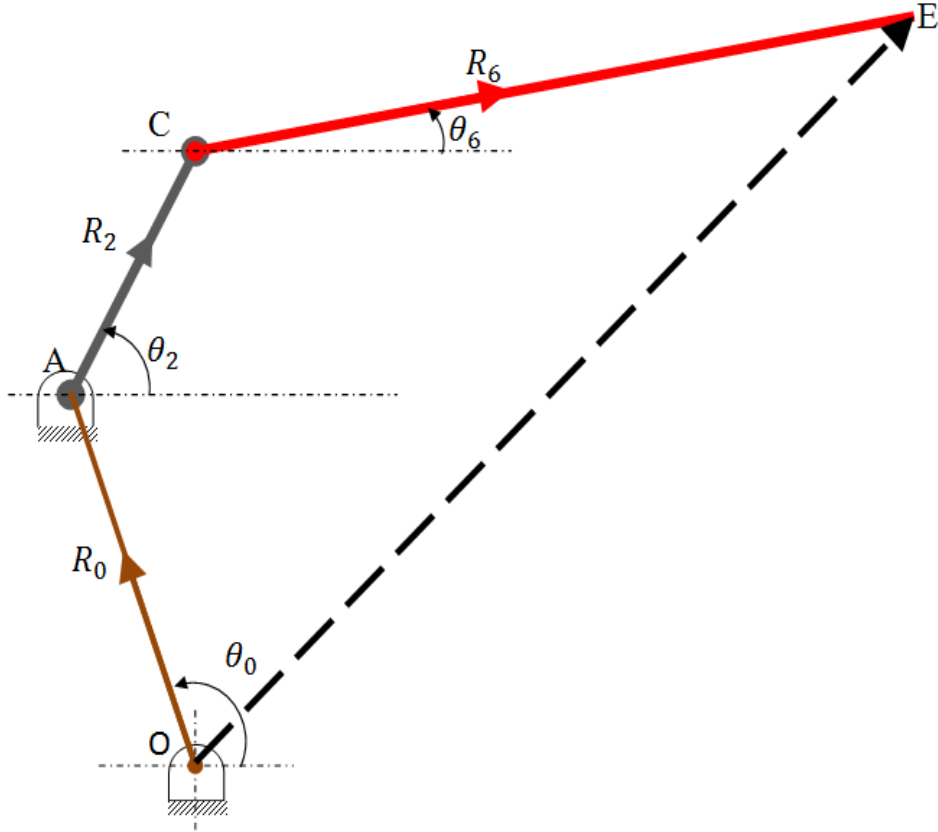


Fig.4.5 Mechanism Vector Representation 2

In vector loop, presented in Fig. 4.5, the position vectors can be written as given in Eq. 10 which has been resolved into two expressions afterwards given in Eq.11 and Eq.12, also termed as position co-ordinate equations. Where first expression depicts the real part and second depicting the imaginary part of complex equation derived using Eq.10.

$$\vec{R}_2 + \vec{R}_0 + \vec{R}_6 = \vec{OE} \quad (10)$$

$$a(\cos \theta_2) + a_0(\cos \theta_0) + d(\cos \theta_6) = x \quad (11)$$

$$a(\sin \theta_2) - a_0(\sin \theta_1) + d(\sin \theta_6) = y \quad (12)$$

Now the orientation equation and position co-ordinate equations are re-written together to represent the system of non-linear simultaneous equations for 5 different co-ordinates using Eq. 13, Eq.14 and Eq.15.

$$c^2 = a^2 + b^2 + d^2 + f^2 - 2ab(\cos(\theta_{1i} + \theta_{2i})) + 2ad(\cos(\theta_{2i} - \theta_{6i})) - 2af(\cos(\theta_{2i} + \theta_{5i})) - 2bd(\cos(\theta_{1i} + \theta_{6i})) + 2bf(\cos(\theta_{1i} - \theta_{5i})) - 2df(\cos(\theta_{6i} + \theta_{5i})) \quad (13)$$

$$a(\cos \theta_{2i}) + a_0(\cos \theta_0) + d(\cos \theta_{6i}) = x_i \quad (14)$$

$$a(\sin \theta_{2i}) - a_0(\sin \theta_{0i}) + d(\sin \theta_{6i}) = y_i \quad (15)$$

where x and y represents the desired co-ordinates of follower ternary link, i represent the index of desired co-ordinates.

4.3.2 APROXIMATE SOLUTION APPROACH

In this approach, Pythagoras theorem equations have been used to evaluate co-ordinate data of ends of mechanism links. At initial stage, input the set of desired co-ordinates (x_{di}, y_{di}) and ground connection co-ordinates (x_0, y_0) and (x_g, y_g) . Then select how much amount of error is feasible between desired and actual co-ordinates and that error is termed here as vicinity error (e_v).

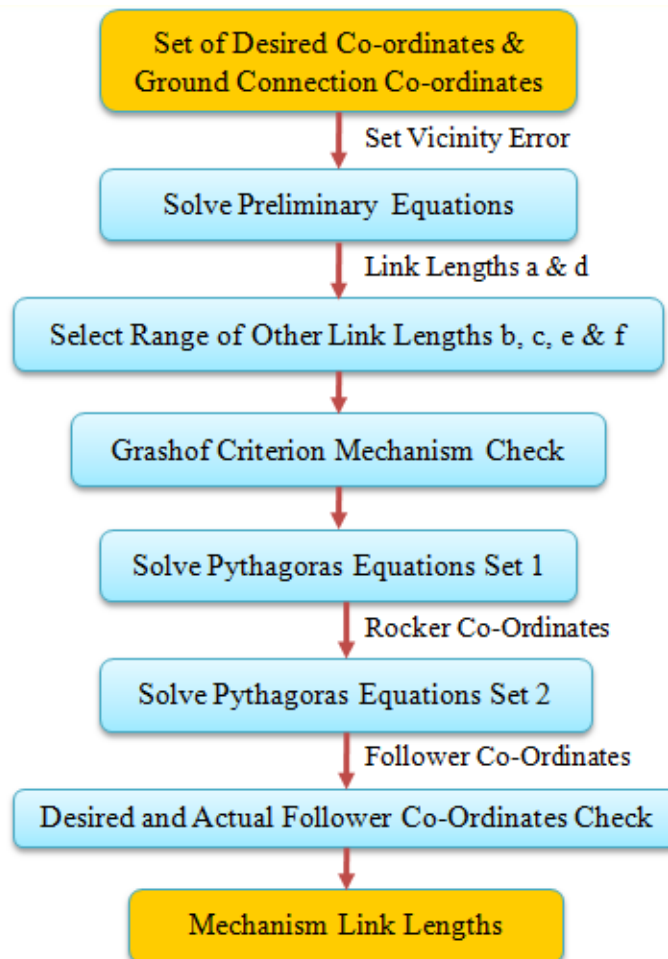


Fig.4.6 Flow Chart for Approximate Solution Approach

Further, preliminary equation as presented in Eq. 16 is solved to find the values of link lengths a and d for complete revolution of crank link and any two desired co-ordinates.

$$(x_{di} - x_0 - (a(\cos \theta_{2i})))^2 + (y_{di} - y_0 - (a(\sin \theta_{2i})))^2 = d^2 \quad (16)$$

After evaluating the values of link length a and d, select an appropriate range of all the other link lengths as explained in Fig. 4.6. Before going ahead with subsequent calculations, only those link length configurations get par which obeys grashof criterion for four bar crank rocker mechanisms. Those link length configurations which obey grashof criterion are then subjected to Pythagoras equations set 1 presented in Eq. 17 and 18 to evaluate rocker co-ordinates (x_r, y_r) .

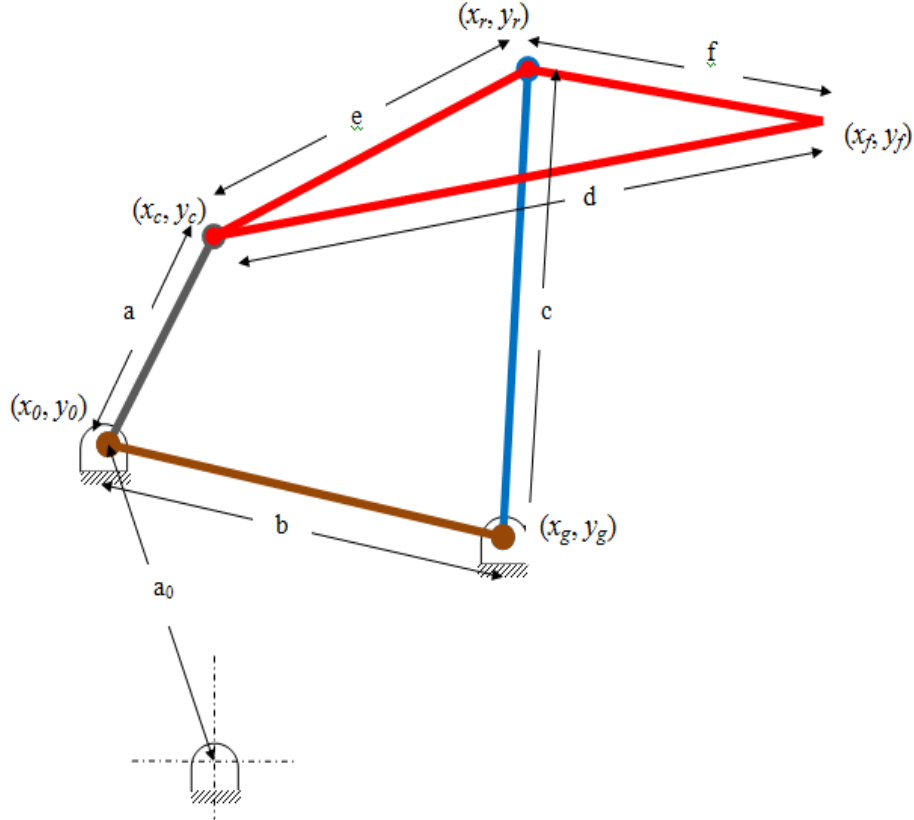


Fig.4.7 Four Bar Mechanism Co-ordinate Diagram

$$(x_r - x_0 - (a(\cos \theta_{2i})))^2 + (y_r - y_0 - (a(\sin \theta_{2i})))^2 = e^2 \quad (17)$$

$$(x_r - x_g - (a(\cos \theta_{2i})))^2 + (y_r - y_g - (a(\sin \theta_{2i})))^2 = c^2 \quad (18)$$

Subsequently the data evaluated was then subjected to Pythagoras equation set 2 presented using Eq. (19) and (20) to evaluate the co-ordinates of follower (x_f, y_f) , which were then stored in an array.

$$(x_f - x_r)^2 + (y_f - y_r)^2 = f^2 \quad (19)$$

$$(x_f - x_0 - (a(\cos \theta_{2i})))^2 + (y_f - y_0 - (a(\sin \theta_{2i})))^2 = d^2 \quad (20)$$

The array elements were subtracted from desired co-ordinate data hence finding the error between them. Only that mechanism link length configuration was selected, which had a value of error lesser than the vicinity error.

4.4 SOLUTION TO MATHEMATICAL MODELS

To solve the mathematical model equations by any approach, the desired co-ordinate and orientation data was required which has been evaluated using Kinect Sensor as presented using Table 4.1. At first, exact solution approach was tried to solve using MATLAB solvers. But it wasn't able to harness any explicit solution for the set of non linear equations. This can be explained by saying that there was no configuration of four bar mechanism link lengths

that could exactly satisfy or pass through the desired co-ordinate position with desired orientations.

Table 4.1 Desired Co-ordinate and Orientation Data

Position No.	x_d (cm)	y_d (cm)	$\theta_6(^{\circ})$
1	48	68	0
2	37	73	10
3	14	92	25
4	6	99	34
5	0	99.7	46

Using approximate solution approach with a vicinity error of 0.5 cm, MATLAB was able to find an explicit solution. The desired range of link lengths were chosen based on iterative process. The phases of evaluation are shown using MATLAB graphs or plots in Fig. 4.7 and final link dimensions of mechanism is presented using Table 4.2.

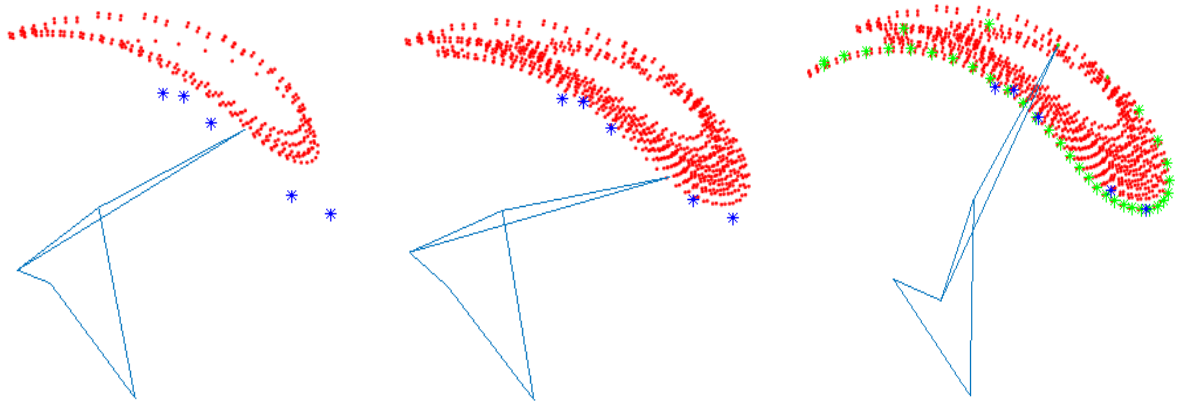


Fig. 4.8 MATLAB Plots during Equation Solving using Approximate Solution Approach

Table 4.2 Final Dimensions of Mechanism Links

Links	Dimensions (cm)
a	16
b	38.6
c	50.9
d	76.1
e	28.3
f	47.8

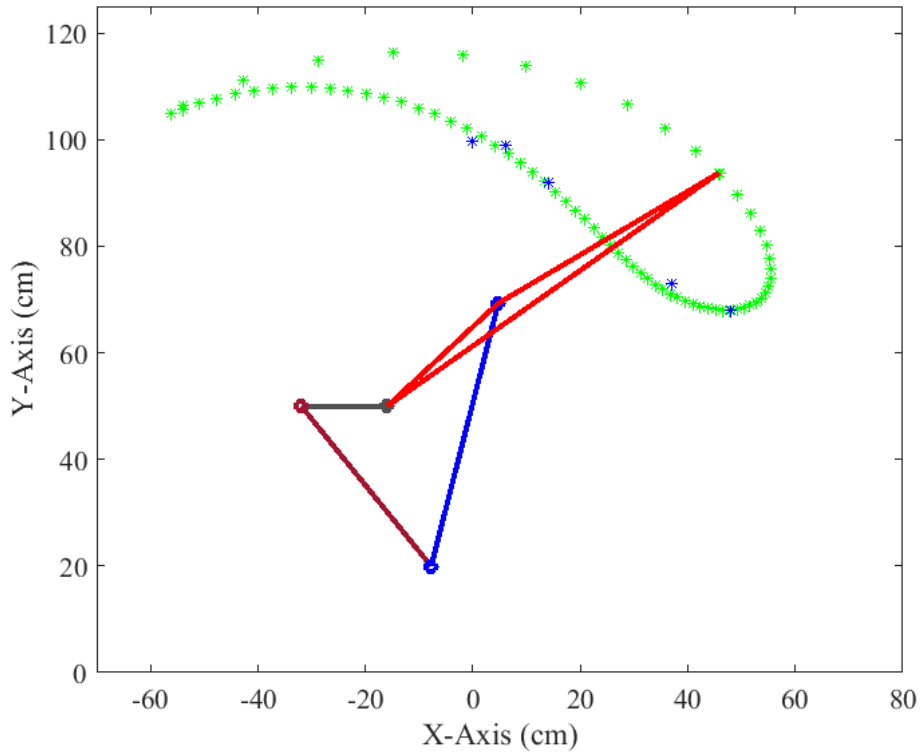


Fig.4.9 Final Configuration of Mechanism and Trajectory Evaluated using Approximate Solution Approach

4.5 SUMMARY

This chapter has discussed two approaches of four bar mechanism synthesis, and that were exact solution and approximate solution approach. While the first approach didn't find an explicit solution, the second approach calculated the mechanism link lengths already discussed in Table 4.2. Using the evaluated link lengths, in the next chapter three dimensional designs and analysis of mechanism links in CAD environment are presented along with dynamic simulation results.

Chapter 5 CAD MODEL GENERATION AND DYNAMIC ANALYSIS

5.1 INTRODUCTION

Generating a CAD model is a vital step in product development process, as it provides the designer, a virtual realization of the product. The evaluated dimensions of the mechanism links from the previous chapter have been used here to produce a CAD model in PTC Creo. Thereon, this chapter discuss the selection of build material, design of mechanism links, design of frame and evaluation of actuator loading capacity based upon the dynamic simulation.

5.2 DESIGN OF MECHANISM LINKS

Aluminium is chosen as the build material for mechanism links, for lowering the weight and increased strength of the mechanism. Based upon the obtained von-misses stress obtained during stress analysis, the shape and thickness of the links has been optimized considering safety factor of 4 or above. Fig. 5.1 depicts the von-misses stress distribution in the original and optimized follower geometry, when the link is subjected to an assumed load of 900N produced by the human weight. The other two ends are assumed to be pin constrained.

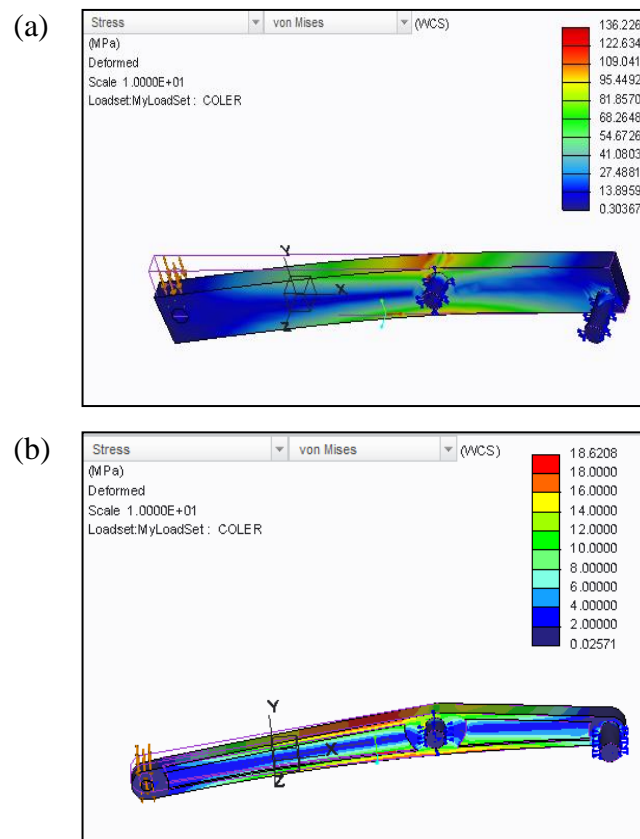


Fig. 5.1 Von Misses Stress Distribution in (a) Draft and (b) Optimized Follower Link

Optimized geometry decreased the level of stresses from 136 MPa to 18 MPa and also reduced the material volume. Similarly taking the account of other links; the CAD model of mechanism is generated as shown in Fig. 5.2. The complete descriptions of mechanism links geometry are given in Annexure.

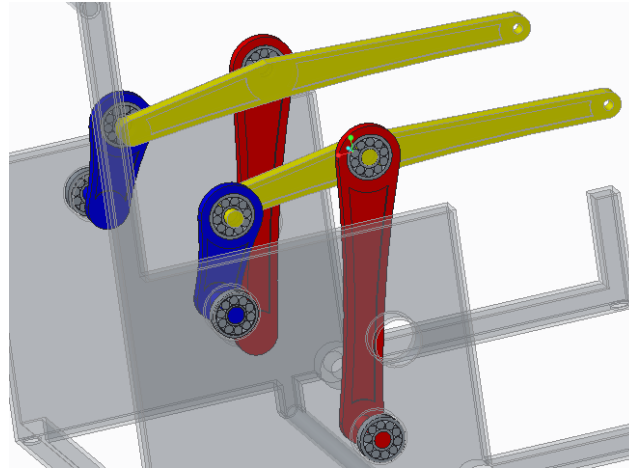


Fig. 5.2 CAD Model of Mechanism

5.3 DESIGN OF FRAME

Frame has been designed considering the weight factor and centre of gravity shift during STS transfer and ambulation. While, lesser weight is to reduce the effort of person during ambulation. Lower centre of gravity is to reduce the chances of imbalance or truffle of the frame in either direction. Aluminium is assumed as build material for weight reduction and overall size is decided based upon centre of gravity analysis in PTC Creo. The desired weight of the frame was selected within a range of 30-40 Kg, with 4 castor wheels to minimize the effort required. Fig 5.3 presents the first version of CAD model of the frame with a mass of 48 Kg.

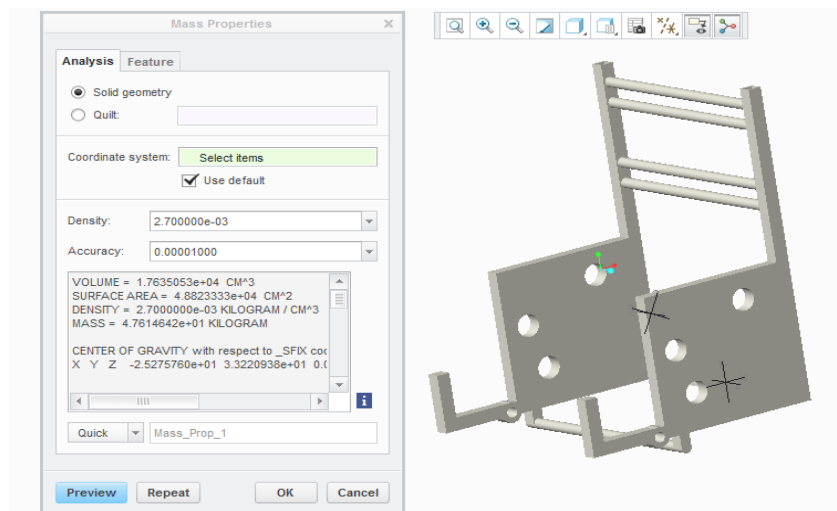


Fig. 5.3 First version of Frame's CAD model

Eventually, the weight of model is reduced by mitigating the aluminium square bar thickness to 0.75cm, resulting to 35 Kg. Now, in the earlier model, CG was found to be -25 cm and 33.2 cm in x and y direction respectively. While CG in y- direction is already low, CG in x-direction needed to be moved behind to match with individual's CG and to avoid trifling of frame in forward direction. Hence, the length of frame has been increased.

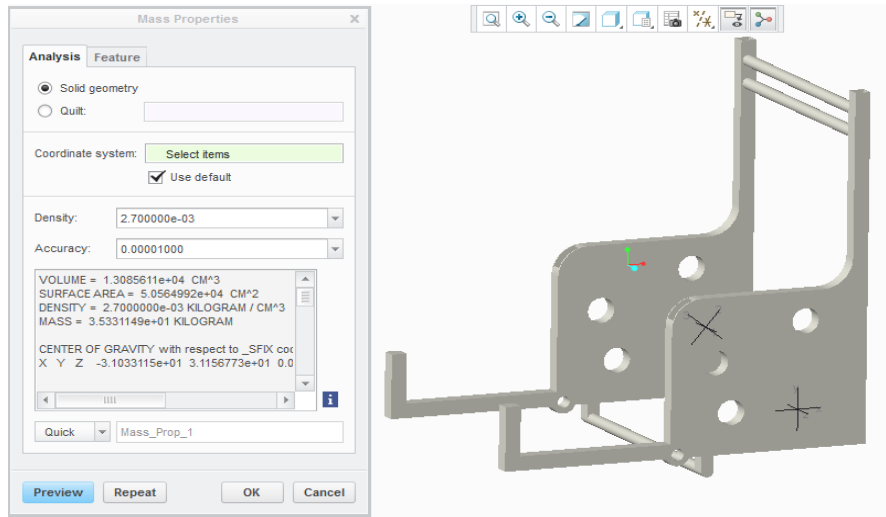


Fig. 5.4 Final version of Frame's CAD model

The increase in the length of the frame resulted in shift of CoG in negative x-direction that is -31 cm, which was near to desired. While based on static physical properties, design of frame was satisfactory for the need. But it was important to check CoG shift during STS transfer by using dynamic simulation assuming gravitational conditions, which has been shown in Fig. 5.5.

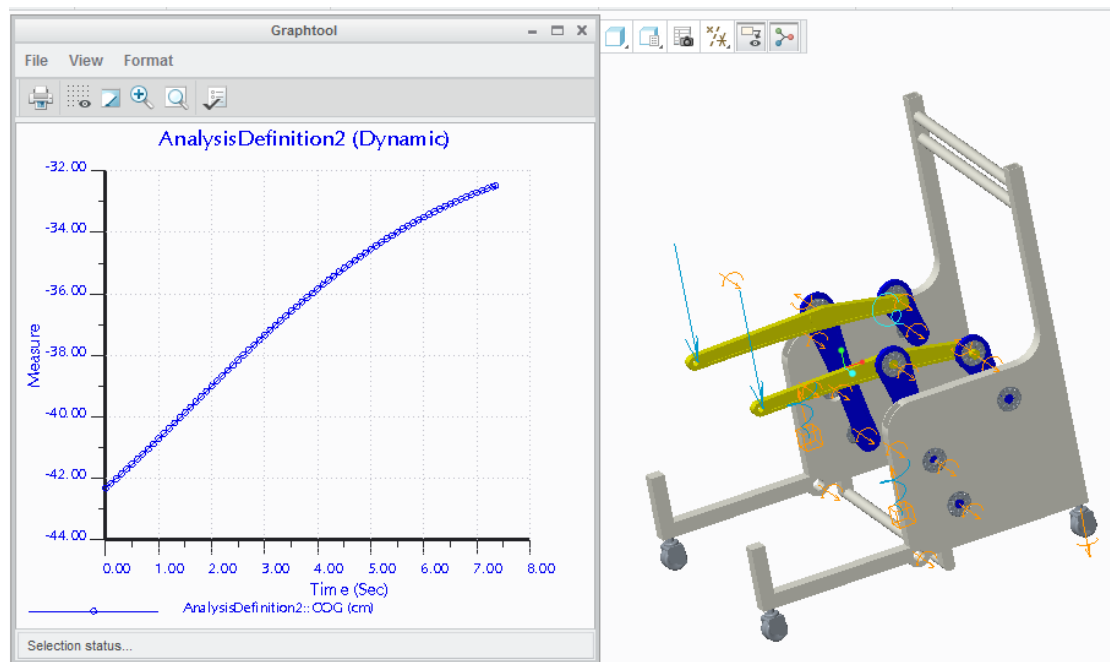


Fig. 5.5 Analysis of Centre of Gravity Shift

5.4 SELECTING ACTUATOR CAPACITY

The four bar mechanism developed, needed to be externally sourced by giving desired actuation to crank link. The actuator capacity required has been evaluated using dynamic simulations of mechanism in PTC Creo. Two different types of actuation modes have been discussed ahead that are stepper motor and electric linear actuators.

5.4.1 TORQUE CAPACITY FOR MOTOR

In this mode of actuation, one stepper motor has been considered as an input source. Stepper motors are considered because the actuation required is not continuous. There was a need to rotate the crank link only by 170-180 degrees to and fro. Two more reason for selecting stepper motor were pace incorporation and weight factor.

Forces of 450 N (F_w) as shown in Fig. 5.6 were assumed on the ends of two follower links each to imitate the forces employed by a individual weighing 90 Kg at max, and crank link was sourced using a motor actuator to find the torque capacity (T_c).

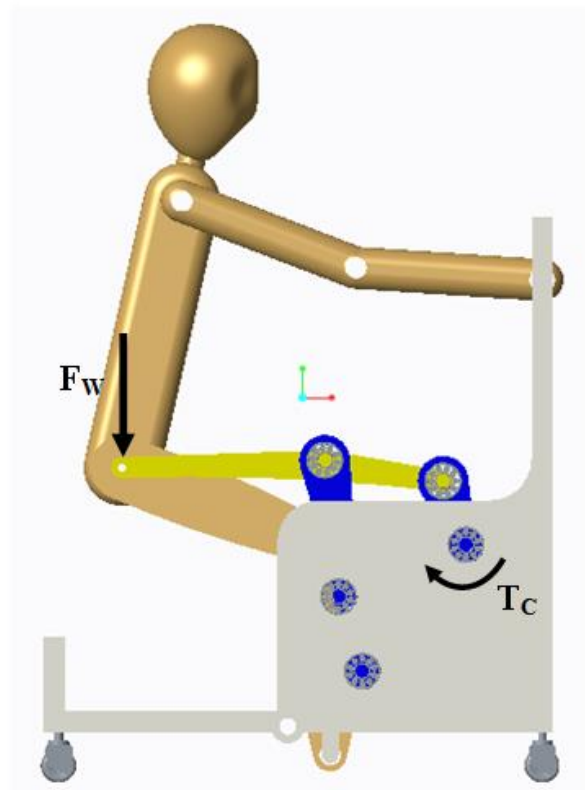


Fig. 5.6 Force and Torque Conditions for Dynamic Simulation

Dynamic simulation results to evaluate torque/motor capacity have been depicted in Fig. 5.7. The maximum actuation torque has been found out to be 583859 cm² Kg /sec² or 58.3 Nm. Hence NEMA [31] 42 can be selected for this mode of actuation, with 3:1 ratio gear box.

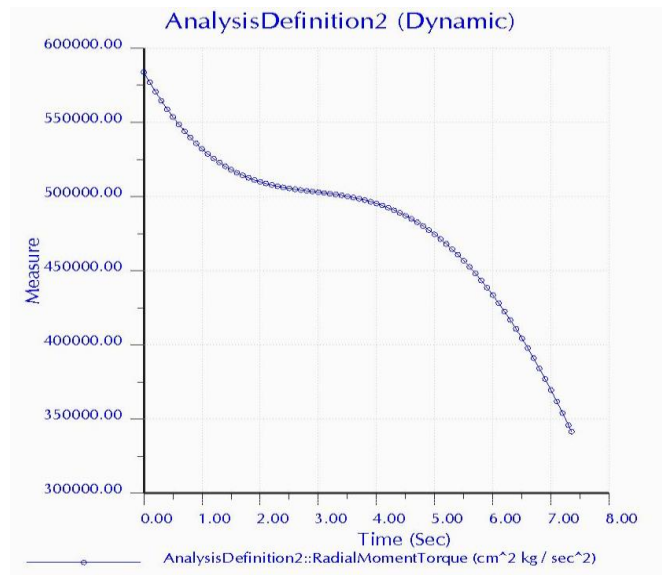


Fig. 5.7 Plot of Motor Torque versus Time

5.4.2 FORCE CAPACITY FOR LINEAR ACTUATOR

In this mode of actuation, two electric linear actuators have been considered as an input source. But it wasn't feasible to directly connect the linear actuator with crank due to possible interferences. Hence, a secondary mechanism needed to be employed to convert linear motion into rotary motion. There is numerous numbers of mechanisms available in literature that could have employed, but to provide this mode of actuation an edge, secondary mechanism have been developed using Linkage as shown in Fig. 5.8.

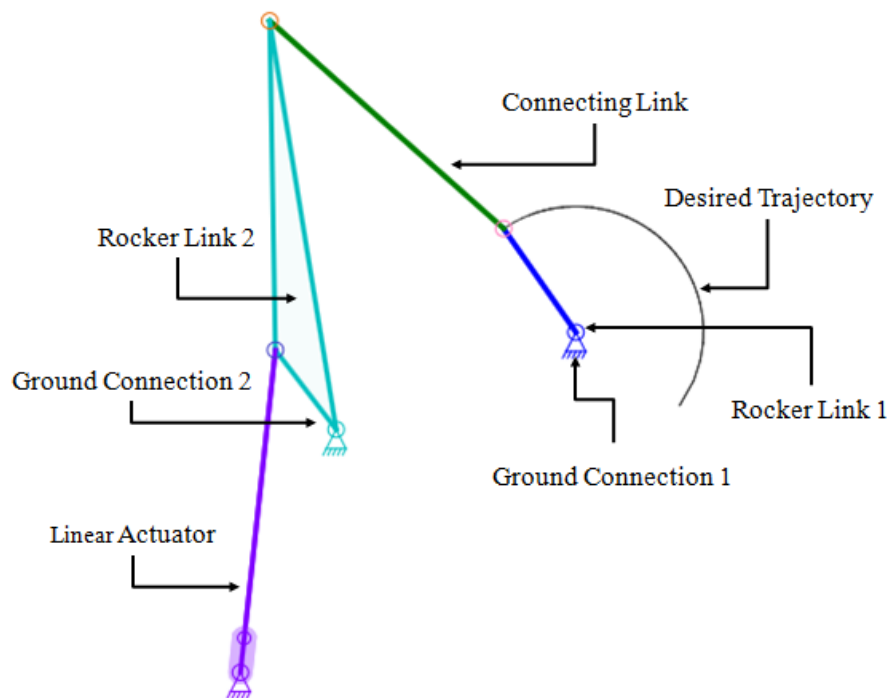


Fig. 5.8 Secondary Mechanism Synthesis using Linkage

The mechanism is unique because of its ability to be converted into a passive human powered mechanism from electrically actuated mechanism. The secondary mechanism is of double rocker type. Here the rocker link- 1 represents the crank link of primary crank rocker mechanism. The links of secondary mechanism are also designed using the similar approach used for designing links of primary mechanism. The final CAD model for employing linear actuators have been shown using Fig. 5.9.

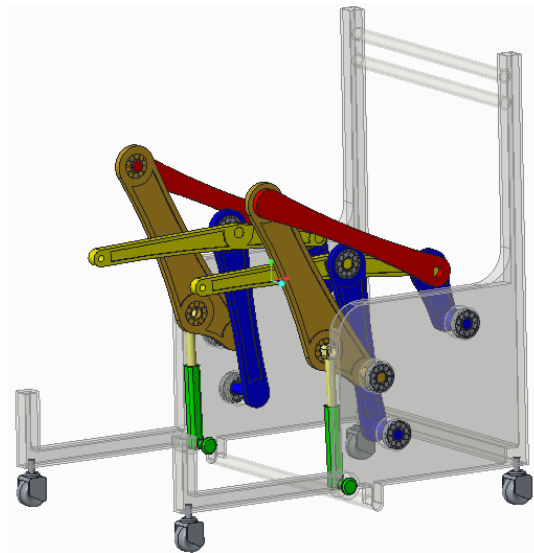


Fig. 5.9 CAD Assembly of Mechanism and Frame

Now after mechanism development and CAD model generation, the required force capacity for linear actuator was to be evaluated. Here also, the dynamic simulations in PTC Creo mechanica have been used.

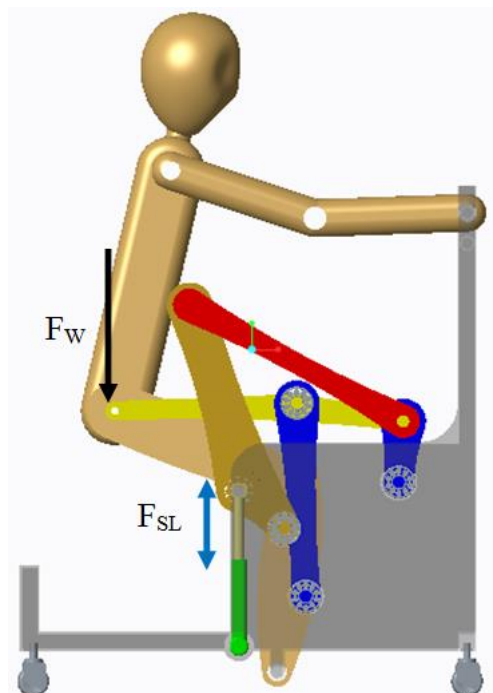


Fig. 5.10 Conditions for Dynamic Simulation for Force Evaluation in Linear Actuator

Forces of 450 N (F_W) as shown in Fig. 5.10 were assumed on the ends of two follower links each to imitate the forces employed by a individual weighing 90 Kg at max, and crank link was sourced using two separate linear actuator to find the force capacity (F_{SL}) of individual actuator. Dynamic simulation results to evaluate actuator load capacity have been depicted in Fig. 5.11.

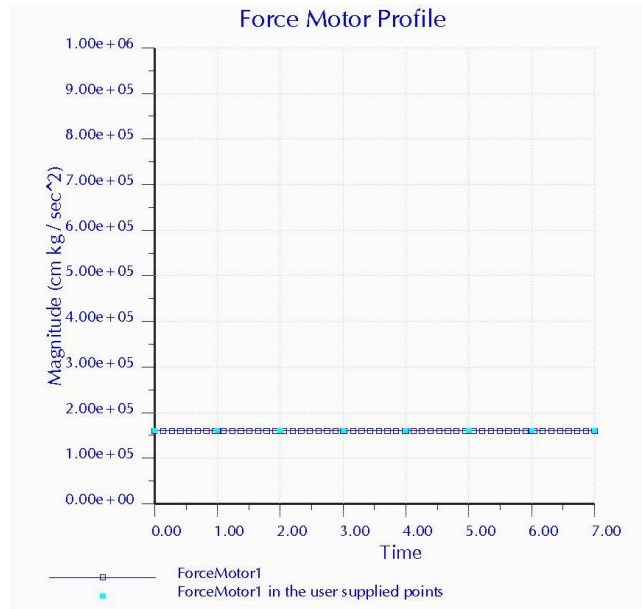


Fig. 5.11 Plot of Linear Actuator Force Capacity versus Time

The maximum force required using each linear actuator has been found out to be 160000 cm Kg /sec² or 1600 N. Hence Linak [32] LA25 which has maximum thrust capacity of 2500 N, maximum speed of 25 mm/sec and stroke length of 2-30 cm can be selected for this mode of actuation.

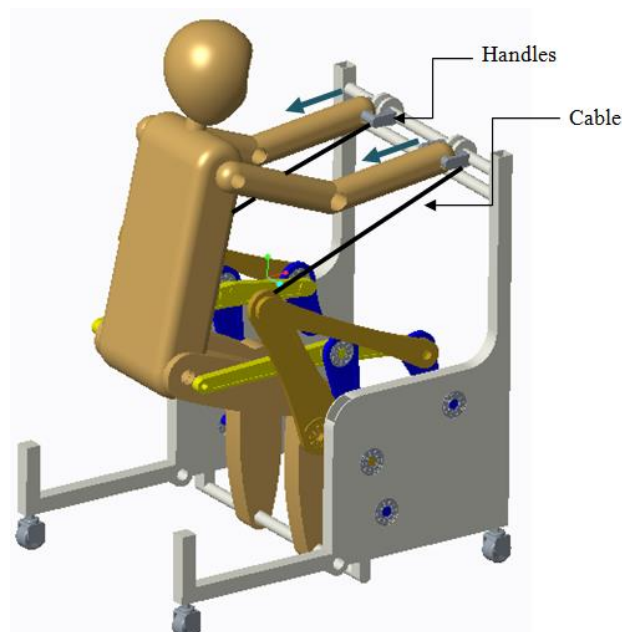


Fig. 5.12 Passive Cable Pulley System

As discussed earlier, the secondary mechanism is so developed that it can facilitate the conversion of electrically actuated mechanism into human powered or passively actuated mechanism. In this mode, the person has to pull the cable connected to rocker of secondary mechanism as explained in Fig. 5.12. The dimensions of rocker of secondary mechanism were decided to provide mechanical advantage in terms of effort required to pull the cables. The pulling force required to be exerted by person is evaluated to be 358 N each, using equality of moments as explicated in Fig. 5.13.

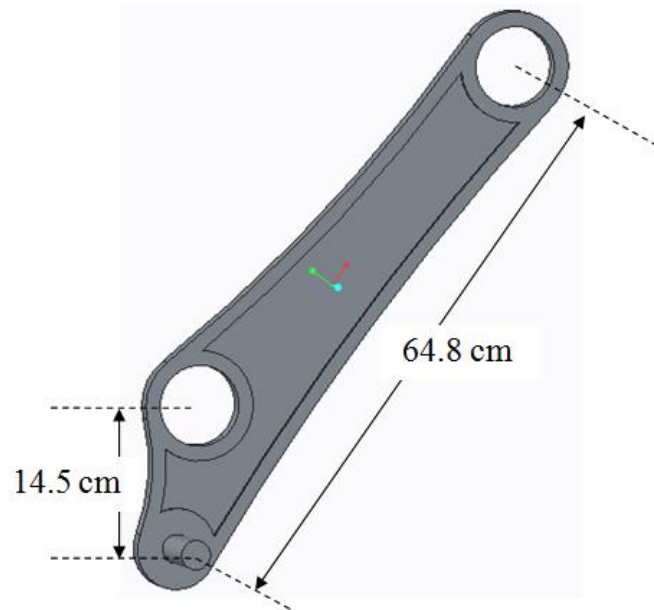


Fig. 5.13 CAD Model of Rocker of Secondary Mechanism

5.5 SUMMARY

The current chapter discussed aluminium as a build material for the mechanism and frame. Von misses stresses were found for designing of mechanism links, centre of gravity shift analysis calculations were used to design the frame and dynamic simulations were performed in PTC Creo to evaluate actuator loading capacity in two different modes of actuation. A passive pulley cable mechanism has also been presented as a third optional mode of actuation. The subsequent chapter will highlight the use of CAD model to produce a scaled prototype using wooden framework and 3D printed mechanism links.

The project aimed to design an assistive device for assisting elderly person during STS and ambulation, which has been successfully concluded. Mechanism link lengths are found using approximate solution approach. Hence, the device so designed includes a four bar crank rocker mechanism, movable frame and electrical actuators based upon the mode of actuation. For actuation using an electrical motor, NEMA 42 stepper motor is proposed. For actuation using linear actuator, Linak LA25 which has stroke length of 8 cm is recommended. For human powered actuation, a cable and pulley system is implemented; where a person is required to exert a pulling force of 358 N. Simulation of working assistive device with electrical linear actuator has been presented in Fig. 6.1.

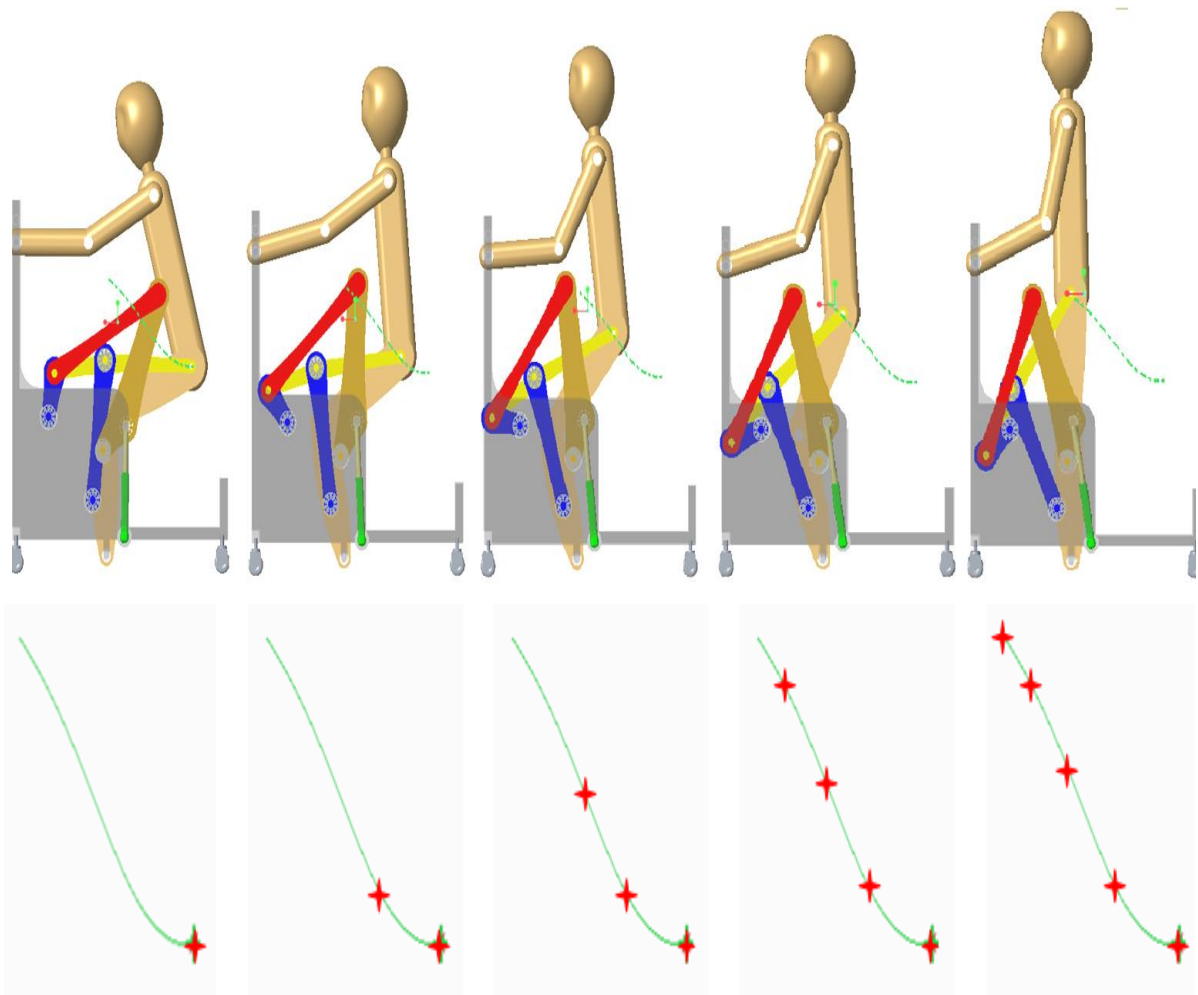


Fig. 6.1 Simulation of Assistive Device following Natural Hip Joint Trajectory

To check the feasibility and practical difficulties related to manufacturing of device, a 1/4th scaled prototype of the device is produced as shown in Fig. 6.2. Frame is fabricated using wood work and the mechanism is fabricated using 3D printing, where ABS is used as building material.

(a)



(b)



Fig. 6.2 Scaled Prototype of Assistive Device Incorporating (a) Primary Mechanism (b) Primary and Secondary Mechanism along Castor Wheels

The major objectives of this projects are successfully completed, but the work can be extended in the following ways.

- Building an original sized prototype, implementing electrical actuator suggested based upon mode of actuation and performing experimentation using patients under medical supervision.
- Implementing control strategies on the scaled prototypes by deploying miniature actuators with feedbacks.
- Designing a modular four bar mechanism for walking aid of patients as presented in Fig. 7.1. The ground connections can be at same position as of STS assitive mechanism connections.

(a)



(b)

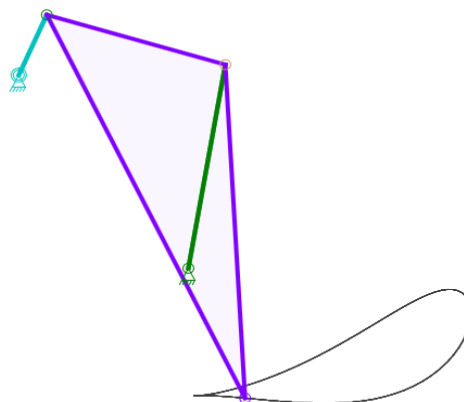


Fig. 7.1 (a) Trajectory of Toe on Treadmill during Normal Walking [33] (b) Four Bar Mechanism for Walking Aid

REFERENCES

- [1] Definition of Ageing:
<https://www.nature.com/subjects/ageing>
- [2] World Population Ageing 2015
http://www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2015_Report.pdf
- [3] Hartigan, Clare, et al. "Mobility outcomes following five training sessions with a powered exoskeleton." *Topics in spinal cord injury rehabilitation* 21.2 (2015): 93-99.
- [4] Purwar, Anurag, et al. "Portable six-bar apparatus for lifting, lowering and self-propelled transit." U.S. Patent No. 8,468,622. 25 Jun. 2013.
- [5] Sadeghi, Mohsen, et al. "Trajectory of human movement during sit to stand: a new modeling approach based on movement decomposition and multi-phase cost function." *Experimental brain research* 229.2 (2013): 221-234.
- [6] Munro, Bridget J., et al. "A kinematic and kinetic analysis of the sit-to-stand transfer using an ejector chair: implications for elderly rheumatoid arthritic patients." *Journal of biomechanics* 31.3 (1997): 263-271.
- [7] Bashford, G., et al. "Effects of using an ejector chair on the mechanics of rising to stand in disabled patients: Clinical implications." *Proceedings of the 2nd Annual Scientific Meeting of the Australasian Faculty of Rehabilitation Medicine, Adelaide.* 1994.
- [8] Biodex Sit2Stand Trainer:
<http://www.biodex.com/physical-medicine/products/mobility-enhancements>
- [9] Médéric, P., et al. "Design of a walking-aid and sit to stand transfer assisting device for elderly people." 7th Int. Conference on Climbing on Walking Robots (CLAWAR'04), Madrid, Spain. 2004
- [10] Médéric, Pascal, et al. "Elderly people sit to stand transfer experimental analysis." *Climbing and Walking Robots* (2006): 953-960.
- [11] Kamnik, Roman, and Tadej Bajd. "Standing-up robot: an assistive rehabilitative device for training and assessment." *Journal of medical engineering & technology* 28.2 (2004): 74-80.
- [12] Chugo, Daisuke, et al. "A motion control of a robotic walker for continuous assistance during standing, walking and seating operation." *Intelligent Robots and Systems, 2009. IROS 2009. IEEE/RSJ International Conference on.* IEEE, 2009.
- [13] Chugo, Daisuke, et al. "Sitting motion assistance on a rehabilitation robotic

- walker." *Robotics and Biomimetics (ROBIO), 2011 IEEE International Conference on*. IEEE, 2011.
- [14] Kim, Inho, et al. "Kinematic analysis of sit-to-stand assistive device for the elderly and disabled." *Rehabilitation Robotics (ICORR), 2011 IEEE International Conference on*. IEEE, 2011.
- [15] Hoang, Khai-Long Ho, and Katja D. Mombaur. "Optimal design of a physical assistive device to support sit-to-stand motions." *Robotics and Automation (ICRA), 2015 IEEE International Conference on*. IEEE, 2015.
- [16] Khan, Mohammed Rajik, Biswaksen Patnaik, and Sonalisa Patel. "Design and Development of a Novel Sit-to-Stand and Mobility Assistive Device for Ambulation and Elderly." *International Conference on Research into Design*. Springer, Singapore, 2017.
- [17] Fattah, Abbas, et al. "Design of a passive gravity-balanced assistive device for sit-to-stand tasks." *Journal of Mechanical Design* 128.5 (2006): 1122-1129.
- [18] Nagai, Kiyoshi, Isao Nakanishi, and Hideo Hanafusa. "Assistance of self-transfer of patients using a power-assisting device." *Robotics and Automation, 2003. Proceedings. ICRA'03. IEEE International Conference on*. Vol. 3. IEEE, 2003.
- [19] Castelli, Gianni, and Erika Ottaviano. "Modelling, simulation and testing of a reconfigurable cable-based parallel manipulator as motion aiding system." *Applied Bionics and Biomechanics* 7.4 (2010): 253-268.
- [20] Nuzik S, Lamb R, VanSant A, Hirt S. Sit-to-stand movement pattern: a kinematic study. *Physical Therapy*. 1986 Nov 1;66(11):1708-13.
- [21] Microsoft Kinect sensor MSXB1033
Available at: <https://developer.microsoft.com/en-us/windows/kinect> (accessed 30 November 2017)
- [22] Flexible Action and Articulated Skeleton Toolkit (FAAST)
Available at: <projects.ict.usc.edu/mxr/faast> (accessed 21 August 2017)
- [23] Purwar A, Desai R. Using Kinect to Capture Human Motion for Mechanism Synthesis, Motion Generation and Visualization. In *ASME 2016 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference 2016 Aug 21* (pp. V05AT07A037-V05AT07A037). American Society of Mechanical Engineers.
- [24] LaBelle K. Evaluation of Kinect joint tracking for clinical and in-home stroke rehabilitation tools. *Undergraduate Thesis, University of Notre Dame*. 2011 Dec.
- [25] Vohralik, Sophie Louise, Annika Rose Bowen, Joshua Burns, Claire Elizabeth Hiller, and Elizabeth Jean Nightingale. "Reliability and validity of a smartphone

- app to measure joint range." *American journal of physical medicine & rehabilitation* 94, no. 4 (2015): 325-330.
- [26] Y. Zhang, H. Hu, H. Zhou, Study on adaptive kalman filter algorithms in human movement tracking, in: Proceedings of the International Conference on Information Acquisition, June–July 2005.
- [27] PTC Creo parametric (Student Edition)
Available at: <https://www.ptc.com/en/academic-program/products/creo> (accessed 30 November 2017)
- [28] Microsoft. (2011, July) Kinect for Windows SDK Beta 1 Programming Guide Version 1.1. pdf.
- [29] MATLAB and Statistics Toolbox Release 2013a, The MathWorks, Inc., Natick, Massachusetts, United States.
- [30] Linkage 2.0
Available at: <http://blog.ectorsquid.com/linkage-mechanism-designer-and-simulator/> (accessed 6 May 2017)
- [31] NEMA Premium Motors
Available at : <https://www.nema.org/Policy/Energy/Efficiency/Pages/NEMA-Premium-Motors.aspx> (accessed 7 February 2018)
- [32] LINAK LA25 Linear Actuator
Available at: <https://www.linak.com/products/linear-actuators/la25/#/productdatasheet> (accessed 18 February 2018)
- [33] Robson, Nina, and Shramana Ghosh. "Geometric design of planar mechanisms based on virtual guides for manipulation." *Robotica* 34.12 (2016): 2653-2668.

A. DIMENSIONS OF FRAME

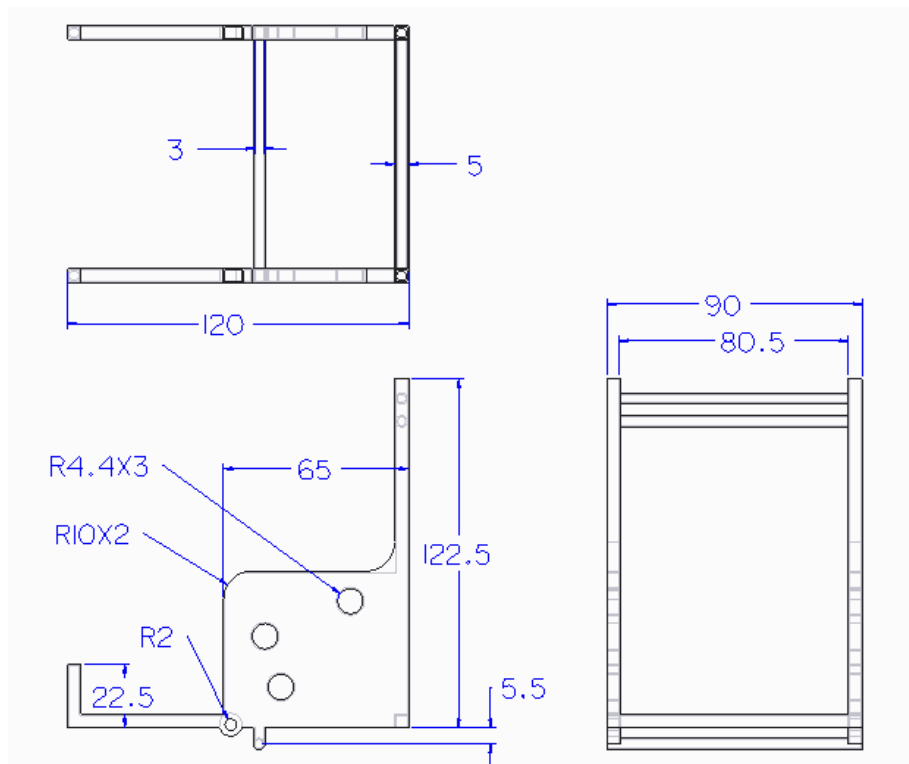


Fig. A1.1 CAD Drawing of Frame

B. DIMENSIONS OF PRIMARY MECHANISM LINKS

B.1 CRANK

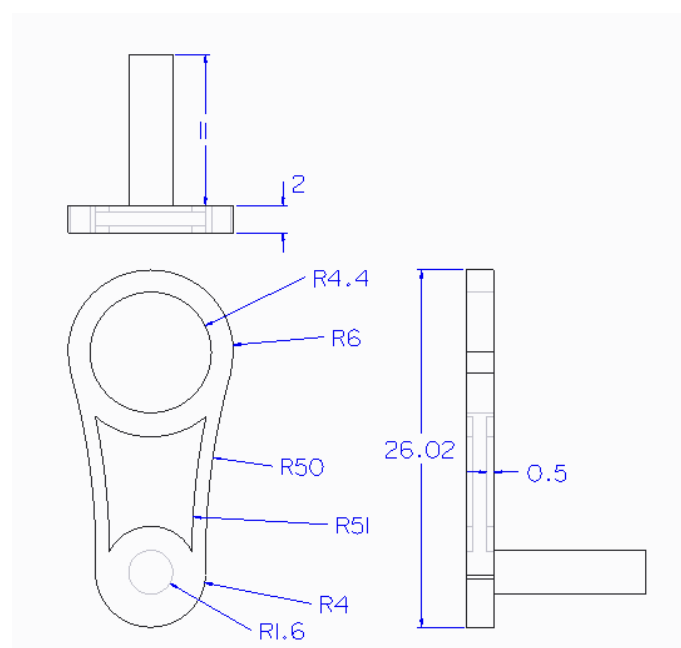


Fig. A1.2 CAD Drawing of Crank Link of Primary Mechanism

C. DIMENSIONS OF SECONDARY MECHANISM LINKS

C.1 CONNECTING ROD

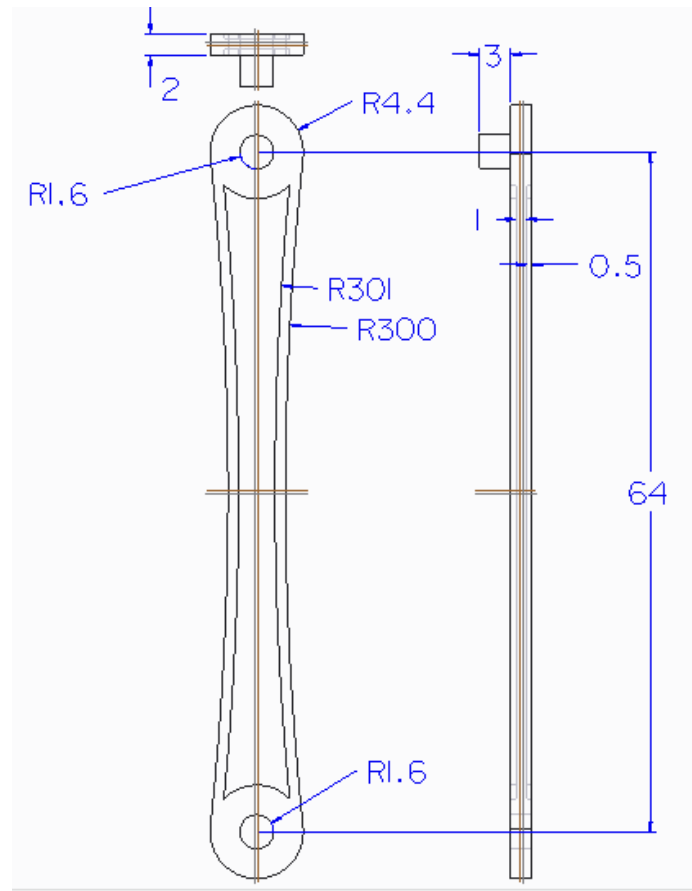


Fig. A1.5 CAD Drawing of Connecting Rod of Secondary Mechanism

C.2 ROCKER

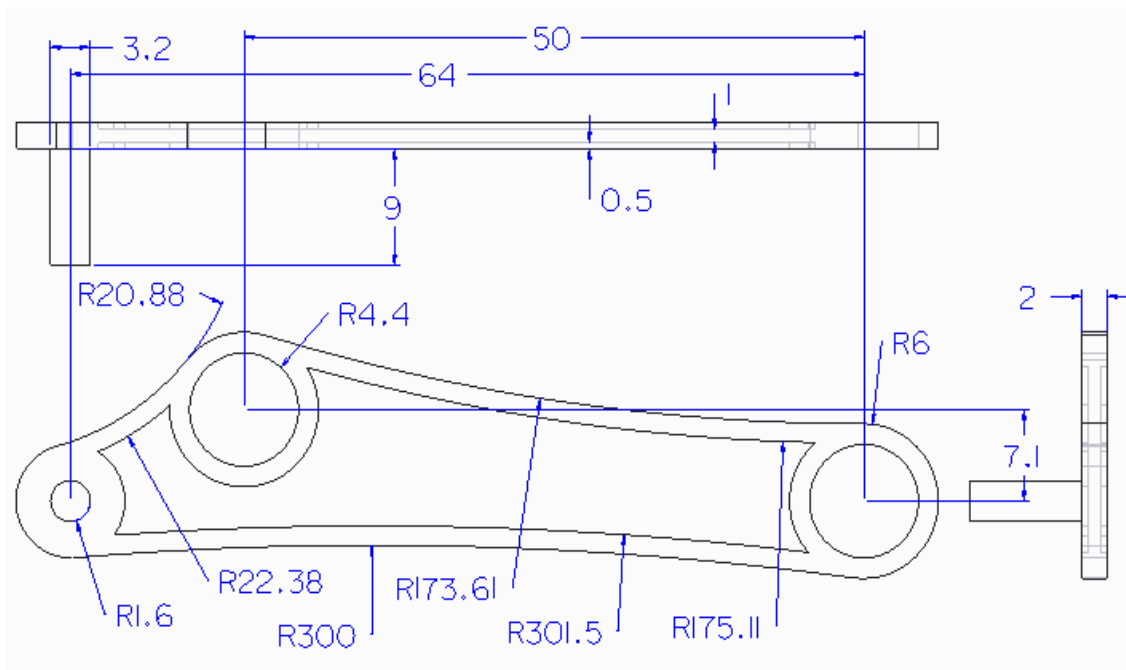


Fig. A1.6 CAD Drawing of Rocker Link of Secondary Mechanism

1. Sukhdeep Singh, Ashish Singla, “Estimation of Joint Trajectories during Sit-to-Stand (STS) Motion using Inertial Measurement Unit (IMU) Sensors in Mobile Devices” Communicated to: Journal of Non-Linear Sciences and Numerical Simulations
2. Sukhdeep Singh, Rituraj Rajpoot, Vansh Bedi, Sandeep Vats, Vineet Srivastava, “Effect of Process Parameters on Shrinkage of Acrylonitrile Butadiene Styrene Parts Fabricated by 3D Printing Process” International Conference on Physics and Mechanics of New Materials and Their Applications (PHENMA-2017), Jabalpur, October 2017
3. Sukhdeep Singh, Ashish Singla, Jaspreet Singh, “Compatibility of Glass Materials with Silicon During Anodic Bonding for Diaphragm based MEMS Capacitive Sensor” Proceedings of International Conference on Advancements in Engineering and Technology (ICAET-2017), Sangrur, March 2017

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